



Monitoring Stream Ecosystems in the Central Alaska Network

Protocol Narrative

Natural Resource Report NPS/CAKN/NRR—2017/1470



ON THE COVER

Hidden Creek and Hidden Creek Lake, Wrangell-St. Elias National Park and Preserve
Photograph by Trey Simmons/NPS

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Trey Simmons

Central Alaska Network
National Park Service
4175 Geist Road
Fairbanks, Alaska 99709

June 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Simmons, T. 2017. Monitoring stream ecosystems in the Central Alaska Network: Protocol narrative. Natural Resource Report NPS/CAKN/NRR—2017/1470. National Park Service, Fort Collins, Colorado.

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Abstract

This protocol describes field, laboratory, and analytical procedures for the Central Alaska Network (CAKN) Stream Monitoring Program. The protocol is composed of two documents, this Protocol Narrative, and a separate document consisting of the 18 Standard Operating Procedures (SOPs) that provide detailed instructions for implementing all aspects of the CAKN Stream Monitoring Program. The SOPs are available at the Integrated Resource Management Applications (IRMA) website: <https://irma.nps.gov/DataStore/Reference/Profile/2215908>. In this Protocol Narrative we provide an overview of the Central Alaska Network, as well as descriptions of the fluvial ecosystems of each of the three park units that constitute the network (Denali National Park and Preserve, Wrangell-St. Elias National Park and Preserve, and Yukon-Charley Rivers National Preserve). We discuss the importance of fluvial systems and processes to network ecosystems and threats to the integrity of these systems due to the effects of climate change and other anthropogenic stressors. We provide an in-depth rationale for the selection of Vital Signs for the Stream Monitoring Program, which include hydrologic regime, composition and distribution of aquatic communities, and water quality. A set of six measurable objectives has been selected to address these Vital Signs:

1. Determine long-term trends for measures of water chemistry at sentinel sites and at larger spatial scales (ecoregion, park, network).
2. Determine long-term trends in measures of water temperature regime at sentinel sites.
3. Determine trends in annual and seasonal flow patterns for the Nabesna River.
4. Use RIVPACS biological assessment models to determine current ecological condition and water quality in selected streams and rivers.
5. Use RIVPACS biological assessment models to determine trends in ecological condition at sentinel sites and at larger spatial scales (ecoregion, park, network).
6. Document the range of chemical, physical, and biological attributes of streams and rivers in the network.

We then provide an overview of all aspects of the stream monitoring program, including survey design, training and field season preparation, field methods, laboratory methods, operational requirements, data management, and data analysis. The methods described in this protocol are designed to be compatible with protocols used by other water resource monitoring programs in Alaska, including the Alaska Department of Environmental Conservation, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and the Bureau of Land Management. Specifically, the survey design, field methods, laboratory methods, and quality assurance/quality control standards described herein are identical to or similar to those spelled out for the Environmental Protection Agency's National Rivers and Streams Assessment program.

Acknowledgments

I would like to acknowledge all of the people who have in one way or another contributed to the development of this protocol. Without their generous help, the protocol would have suffered greatly. These include, but are not limited to, G. Burkart, J. D. Ostermiller, S. A. Goeking, A. Anderson, D. Galbraith, J. Schmidt, A. Larsen, H. Kristenson, A. Peck, and C. Arp. I would also like to acknowledge the authors of freshwater monitoring protocol published by the North Coast and Cascades Network and the Central Alaska Network Shallow Lakes Protocol, which I found extremely helpful, especially in revising early drafts of this protocol. Extra thanks to M. McCluskie for both substantial intellectual contributions and emotional support. Any mistakes or remaining weaknesses in the protocol are entirely my responsibility.

List of Acronyms

ACWA	Alaska Clean Water Actions
ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
AKMAP	Alaska Monitoring and Assessment Program
APHA	American Public Health Association
ATV	All-terrain vehicle
BLM	Bureau of Land Management
CAKN	Central Alaska Network
CCAL	Cooperative Chemical Analytical Laboratory
DEM	Digital Elevation Model
DENA	Denali National Park and Preserve
DIC	Deviance Information Criterion
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
GIS	Geographic Information System
GPRA	Government Performance and Results Act
GPS	Global Positioning System
GRTS	Generalized Random Tessellation Stratified
HDPE	High Density Polyethylene
I&M	Inventory and Monitoring
IBI	Index of Biological Integrity
IBO	Information Bearing Object
IQR	Interquartile Range
IRMA	Integration of Resource Management Applications
IT	Information Technology
LTEM	Long Term Ecological Monitoring program
MSDS	Material Safety Data Sheet
NAWQA	National Water Quality Assessment
NHD	National Hydrology Dataset
NMDS	Nonmetric Multidimensional Scaling
NPS	National Park Service
NRDS	National Resource Data Series
NRSA	National Rivers and Streams Assessment

List of Acronyms (continued)

NRTR	Natural Resource Technical Report
NWR	National Wildlife Refuge
OTU	Operational Taxonomic Unit
PCA	Principal Components Analysis
PRISM	Parameter-elevation Regressions on Independent Slopes Model
QA/QC	Quality Assurance/Quality Control
RIVPACS	River Invertebrate Prediction and Classification System
SOP	Standard Operating Procedure
SQL	Structured Query Language
UNESCO	United Nations Educational, Scientific and Cultural Organization
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WRST	Wrangell-St. Elias National Park and Preserve
WSA	Wadeable Streams Assessment
YUCH	Yukon-Charley Rivers National Preserve

Overview and Objectives

This Protocol Narrative provides an overview and rationale for the Central Alaska Network (CAKN) stream ecosystem monitoring program. The narrative begins with a rationale for monitoring stream and river ecosystems, followed by a set of monitoring questions and objectives for the program. Next is a description of each of the network parks and their stream and river resources, along with an overview of extant data available at the time the program was initiated. Following this is a detailed rationale for the selection of the stream-related Vital Signs, which constitute the organizing foci of the monitoring program. These Vital Signs include hydrologic regime, composition of aquatic communities, and chemical and biological measures of water quality (including temperature). I then discuss how this program is linked to other regional and national monitoring programs and provide an extensive discussion of the program's survey design, including an overall rationale for the final survey design, as well as discussions of the sample population, stream selection process, and sampling frequency. Finally, there is an overview of each of the 18 Standard Operating Procedures (SOPs) that constitute the heart of the monitoring program, with a particular emphasis on data management, analysis methods, and trend detection. The Standard Operating Procedures for the CAKN stream monitoring program are listed in Table 1. The field and laboratory methods described in these SOPs, as well as the relevant quality assurance standards, are based closely on the methods and standards of the Environmental Protection Agency's (EPA) National Rivers and Streams Assessment program. This is a national long-term monitoring and assessment program that grew out of the EPA's Environmental Monitoring and Assessment Program (EMAP), which was active from 1990–2006. Using methods and generating data that are compatible with the National Rivers and Streams Assessment is a central objective of the CAKN stream monitoring program.

Table 1. List of Standard Operating Procedures (SOPs) referred to in this Protocol Narrative. The SOPs are published in a separate document.

SOP Number	Title
SOP 1	Field Season Preparation
SOP 2	Sampling Design and Site Selection
SOP 3	Continuous Monitoring of Temperature
SOP 4	Training
SOP 5	Field Trip Mobilization
SOP 6	Using the GPS
SOP 7	Multiparameter Sonde Calibration and Maintenance
SOP 8	Field Methods for Water Chemistry and Biological Sampling, and Habitat Characterization
SOP 9	Spherical Panoramic Photography
SOP 10	Discharge Measurement
SOP 11	Decontamination
SOP 12	Water Chemistry Laboratory Procedures
SOP 13	Diatom Laboratory Procedures
SOP 14	Macroinvertebrate Laboratory Procedures

Table 1 (continued). List of Standard Operating Procedures (SOPs) referred to in this Protocol Narrative. The SOPs are published in a separate document.

SOP Number	Title
SOP 15	Data Management
SOP 16	Field Season Demobilization
SOP 17	Data Analysis and Reporting
SOP 18	Revising the Protocol

The CAKN is part of the National Park Service (NPS) Inventory and Monitoring (I&M) Program. The Inventory and Monitoring Program is the result of the National Parks Omnibus Management Act, which was passed by Congress in 1998. This act directs the National Park Service to “establish baseline [resource] information and to provide information on the long-term trends in the condition of National Park System resources.” To accomplish this formidable task, the NPS has grouped parks into 32 networks based upon broad ecological similarities. Four of these networks are in Alaska. The CAKN (Figure 1) is composed of three Alaskan conservation units: Wrangell-St. Elias National Park and Preserve (WRST), Denali National Park and Preserve (DENA), and Yukon-Charley Rivers National Preserve (YUCH). The network encompasses 21.7 million acres spread over 150,000 square miles, with 11.8 million acres of designated wilderness, all of it in DENA and WRST. Yukon-Charley Rivers National Preserve contains 1.8 million acres of suitable wilderness lands (72 percent of its total area), where management is the same as in designated wilderness. Based on total area, the CAKN represents 25 percent of the land in the national park system. These parks encompass a number of physiographic and climatic regions, including 12 of Alaska’s 32 ecoregions (Nowacki et al. 2002), and consequently exhibit a wide diversity of stream and river types. Elevations in the CAKN range from sea level to over 20,000 feet. Biomes range from boreal to maritime with a substantial transition zone. Most of WRST and DENA and all of YUCH have continental climates (relatively low precipitation, long extremely cold winters, and short hot summers). The south side of the Alaska Range in DENA and the coastal areas of WRST have a maritime climate (cool wet summers, relatively mild winters with extensive snowfall).

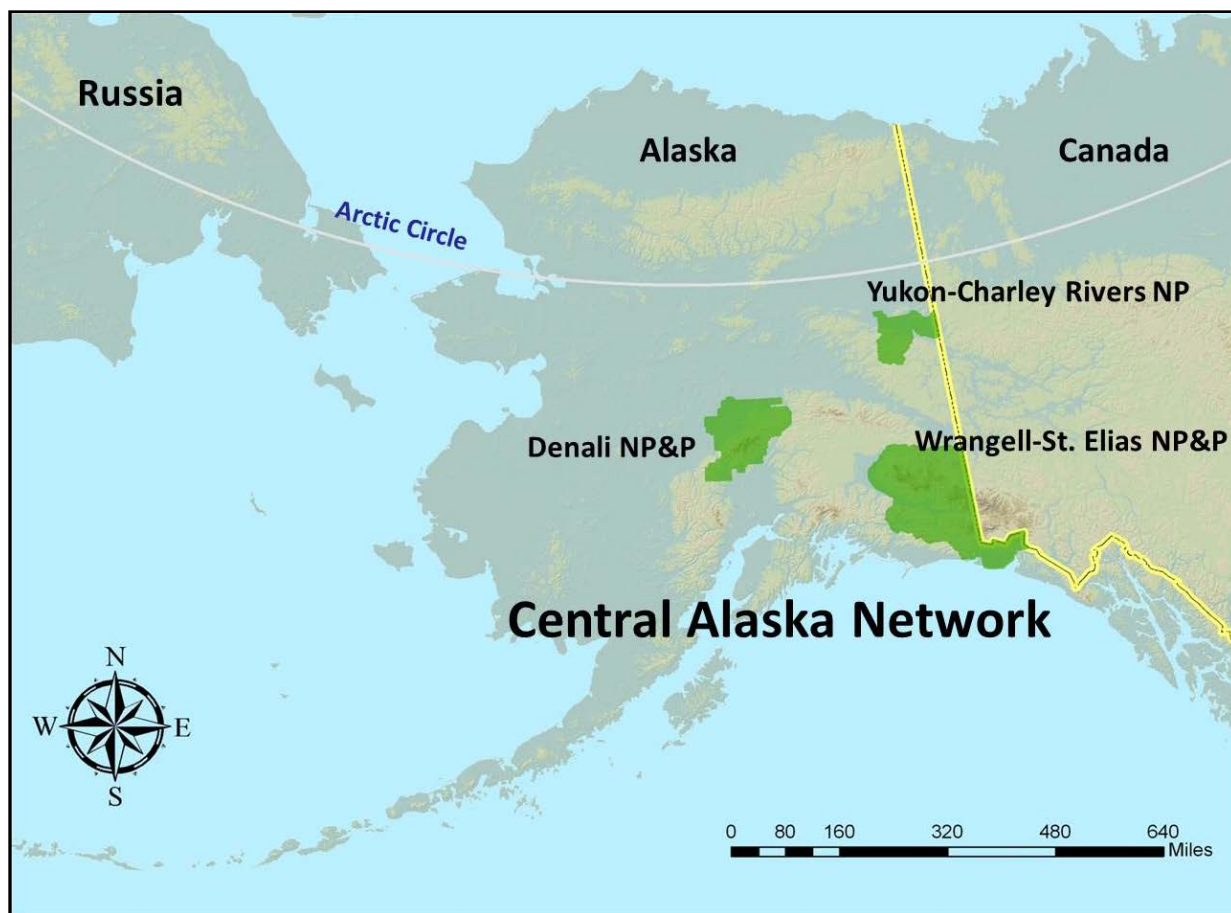


Figure 1. Map of the Central Alaska Network.

We have specifically chosen to focus the CAKN monitoring program on measures of general ecological structure and function because our parks are relatively pristine and unstudied. In so doing, the CAKN program falls predominantly under servicewide goals focused on determining status and trends of ecosystem condition, understanding the dynamics of park ecosystems, and providing data to meet legal mandates (goals #1, #3, and #4, see MacCluskie and Oakley 2005). Ecological Vital Signs may occur at any level of ecological organization; thus, several of the Vital Signs we monitor are of a large-scale ecological scope. While many long-term ecological monitoring programs have focused on local or regional-scale anthropogenic causes of change, direct human effects tend to be more limited in our systems. However, scientists are already observing changes in high-latitude ecosystems due to climate warming; moreover, arctic and subarctic environments may be especially vulnerable to even slight shifts in temperature regimes (e.g., National Assessment Synthesis Team 2000). Because of their size, remote and protected status, and resultant relatively pristine condition, few regions offer the environmental monitoring opportunity and promise that is possible in the arctic and subarctic parks of Alaska. The relatively untouched nature of these vast parklands provides the CAKN with important baselines to measure and evaluate the direction and magnitude of changes brought about by human influences on regional, national, and global scales.

An important component of the CAKN monitoring program is flowing water systems (streams and rivers). The rationale for this focus is manifold. Fluvial processes are central to the hydrologic cycle and the evolution of all landscapes, including the CAKN (e.g., Allan 2000; Wetzel 2001). In addition to providing habitats that directly support hundreds of aquatic and semi-aquatic species, including mammals, birds, fish, macroinvertebrates, algae, and macrophytes, the streams and rivers of the CAKN also create and maintain a mosaic of riparian and floodplain habitats that is critical for numerous terrestrial plant and animal species, as well as recharging water levels in floodplain lakes. While fluvial fish populations provide an important source of energy to a number of terrestrial species, stream and river ecosystems also provide substantial direct subsidies to terrestrial food webs in the form of emergent adult aquatic insects (Nakano and Murakami 2001; Baxter et al. 2005) and during periods of overbank flow (Emmerton et al. 2007). Many streams and rivers in the CAKN support large runs of anadromous salmon and hence are critical for the delivery of substantial marine-derived nutrient subsidies to lotic, lacustrine, riparian, and upland terrestrial ecosystems (e.g., Naiman et al. 2002, Hocking and Relmchen 2006; Rex and Petticrew 2008). Finally, there are several regulatory requirements that compel the National Park Service to report on the water quality of network streams and rivers. The NPS Government Performance and Results Act (GPRA) goal for water resources requires that parks report on “impaired waters” as defined by section 303(d) of the Clean Water Act. Other legal mandates for the protection of and reporting on water quality and aquatic resources by the National Park Service include various sections of the Clean Water Act (1972), the Alaska National Interest Lands Conservation Act (1980), the NPS Organic Act (1916), the Water Quality Improvement Act (1970), and the National Environmental Policy Act (1969), as well as a number of amendments and Executive orders. In addition, the NPS is required to report on water bodies that fall under Tier 2 of the state of Alaska’s tiered water body classification (MacCluskie and Oakley 2005).

Stream and river ecosystems and the biotas that inhabit them are influenced by physical and biological factors that operate over a vast range of spatial and temporal scales (e.g., Allan 2000). While substantial, even extreme, differences are apparent among streams in different settings, the processes that shape them appear to be general. For example, inputs and transformations of energy, nutrients, sediment, and other material are critical in all stream and river systems. Similarly, although regional species patterns and interactions between species at local scales are important drivers of lotic community structure, regional and local-scale environmental gradients tend to dominate (*sensu* Poff 1997). These broad commonalities facilitate the development of a landscape-scale monitoring program by allowing the selection of a relatively small number of indicators or metrics that are capable of providing information about status and trends among a large number of diverse ecosystems, each of which may be subject to one or more of a wide array of potential stresses of varying magnitude.

Stream and river ecosystems are known to be sensitive to the effects of anthropogenic stressors, ranging from global warming to more localized activities such as resource extraction and agriculture. Because of the generally low levels of industrialization near the CAKN parks, it is reasonable to expect that the effects of global warming will be paramount. The expected effects of warming on these ecosystems are manifold and complex, but include higher water temperatures, changes in the

timing and extent of glacier meltwater contributions, changes in the timing and magnitude of precipitation and snowmelt (altering the hydrologic regime), increasing fire frequency, increasing length of the open-water season, degrading permafrost (expected to alter hydrologic flowpaths as well as sediment and nutrient inputs), changes in riparian vegetation (potentially altering allochthonous energy fluxes, habitat structure and insolation), changes in ocean conditions (potentially altering inputs of marine-derived nutrients) and colonization by exotic species (e.g., Carpenter et al. 1992; Rouse et al. 1997; Meyer et al. 1999; Barnett et al. 2005; Hinzman et al. 2005; Heino et al. 2009). Other effects of global industrialization can also be expected, including wet and dry deposition of mercury, nitrates, and other airborne pollutants (Gubala et al. 1995, Landers et al. 2008). More localized impacts may also occur. These include the effects of roads and other infrastructure associated with park visitation. All-terrain vehicle (ATV) use is of particular concern in Wrangell-St. Elias, which features some 600 miles of ATV trails (Happe et al. 1998). Also of potential concern are the effects of potential urbanization near to (e.g., the Copper River Basin for WRST) and/or upstream of (e.g., the Canadian Yukon for YUCH) CAKN parks, as well as local sources of air pollution from power plants and vehicle traffic and the commercial, subsistence, and sport harvest of fish. Finally, CAKN parks contain substantial inholdings of private and Alaska Native Corporation lands, some of which include active mining claims. These claims may be developed in the future, potentially leading to impacts of uncertain magnitude. An important component of the CAKN stream and river monitoring program will be the development of robust tools to allow park managers to assess the effects of these impacts on fluvial ecosystems, both at specific sites of concern as well as park-wide.

Fluvial ecosystems in the CAKN vary from large glacial rivers to small tundra streams, from boreal streams underlain by permafrost to coastal streams flowing through temperate rainforest. Much of the flowing water in the CAKN eventually drains into the Yukon River; however, the network also includes substantial portions of the Copper and Susitna River drainages and a small part of the Kuskokwim basin, as well as numerous coastal streams along the Malaspina Forelands. Although the total length of rivers and streams in the CAKN is currently unknown, estimates based on analyses of the National Hydrography Dataset (NHD) place the total at greater than 28,000 miles, or at least one third of all the stream miles in the national park system (Dean Talbot, NPS, pers. comm.). Current efforts to update the NHD for Alaska to 1:24,000 resolution will increase the total mapped stream length substantially (Kacy Krieger, University of Alaska Anchorage, pers. comm.).

The only river in the CAKN that has been designated as a National Wild and Scenic River is the Charley River in YUCH, although many network rivers have been proposed for Wild and Scenic designation (Table 2). The state of Alaska has designated no Outstanding Natural Resource Waters in these (or any other) parks. Nevertheless, most of the flowing waters in the CAKN are relatively pristine, particularly in comparison to streams and rivers in the Lower 48, despite a history of placer mining in all three park units. With the exception of a relative handful of heavily impacted systems (present in each park unit), stream and river ecosystems in the CAKN are in general structurally and functionally intact. Nevertheless, an extensive history of mining, especially in YUCH, the Kantishna Hills district in DENA, and the Chisana and McCarthy districts in WRST remains an important source of impairment to a subset of CAKN flowing waters. For example, there are over 400

abandoned mine sites in WRST. Although sections of only two CAKN streams have been designated as impaired under Section 303(d) of the Clean Water Act, a larger number may have some degree of impact from the effects of placer mining.

Table 2. Central Alaska Network rivers in the Nationwide Rivers Inventory (proposed for inclusion in the National Wild and Scenic Rivers system)

Wrangell-St. Elias National Park and Preserve	Yukon-Charley Rivers National Preserve
Beaver Creek	Yukon River
Bremner River	Kandik River
Chisana River	Nation River
Chitistone River	Twentymile River
Copper River	—
Hanagita River	—
Kuskulana River	—
Nabesna River	—
Nizina River	—
Tana River	—
Tebay River	—
White River	—

Monitoring Questions

Are stream temperature regimes changing over time? Such change might be manifested in a number of ways, including changes in monthly, seasonal, or annual measures such as mean, median, maximum or minimum temperature, or in an increase or decrease in temperature variability.

Is stream water chemistry changing over time? Different stream types are likely to respond in different ways (magnitude and direction).

Are hydrologic regimes changing over time? Such changes might be manifested as alteration of seasonal or annual flow statistics (e.g., mean, maximum flow) or in the timing of maximum or minimum flows.

Are aquatic communities changing over time? Are native species disappearing from some streams? Or more broadly, is the distribution of species changing across the network? Are new species appearing? Are stream communities becoming more variable in terms of species composition?

Is stream ecosystem condition changing over time? Again, different stream types are likely to respond in different ways (magnitude and direction).

Monitoring Goals

The primary goals of the CAKN stream monitoring program are to:

1. Improve understanding of stream ecosystems in the network by documenting the range of chemical, biological, and physical attributes in network streams and rivers.
2. Understand how temperature regimes in network streams and rivers may be changing.
3. Determine the current status of, and future trends in, ecosystem condition in network streams and rivers.
4. Determine the current status of, and future trends in, the water chemistry of network streams and rivers.
5. Characterize the current hydrologic regime of the Nabesna River and detect changes in that hydrologic regime.
6. Provide timely and high-quality data to park managers.
7. Collect data that are compatible with data collected by other state and federal agencies, in particular the EPA National Rivers and Streams Assessment.

Measurable Objectives

To address our monitoring questions and accomplish these monitoring goals, we have established six measurable objectives:

1. Determine long-term trends for measures of water chemistry at sentinel sites and at larger spatial scales (ecoregion, park, network).
2. Determine long-term trends in measures of water temperature regime at sentinel sites.
3. Determine trends in annual and seasonal flow patterns for the Nabesna River.
4. Use RIVPACS biological assessment models to determine current ecological condition and water quality in selected streams and rivers.
5. Use RIVPACS biological assessment models to determine trends in ecological condition at sentinel sites and at larger spatial scales (ecoregion, park, network).
6. Document the range of chemical, physical, and biological attributes of streams and rivers in the network.

Descriptions of CAKN Park Units

Wrangell-St. Elias National Park and Preserve

At 13.2 million acres, Wrangell-St. Elias National Park and Preserve (WRST) is the largest national park in the United States (Figure 2). The landscape is dominated by four mountain ranges; the Alaska, Wrangell, St. Elias, and Chugach, which together create an extensively glaciated landscape containing multiple peaks over 16,000 feet, including 18,000 foot Mt. St. Elias, as well as the largest nonpolar icefield in the world. WRST is also one of four contiguous conservation units spanning the U.S.-Canada border and covering approximately 32 million acres. This area, which includes Glacier

Bay National Park on the U.S. side, as well as Kluane National Park and Alsek-Tatshenshini Provincial Park on the Canadian side, has been designated by the United Nations as an International World Heritage Site. Together these parks constitute the largest internationally protected area in the world. Hydrologically, WRST is dominated by the influence of the area's extensive glaciers and icefields, which cover over 25% of the park. There are six major drainages in the park; the Copper, Chitina, Bremner, White, Chisana and Nabesna Rivers. Of these, the Chitina and Bremner Rivers drain into the Copper, which ultimately empties into the Gulf of Alaska, whereas the White, Chisana, and Nabesna Rivers all drain into the Yukon River and thence to the Bering Sea. All six of these major rivers are dominated by glacial meltwater; they are turbid, highly dynamic, and flow in wide, extensively braided channels.

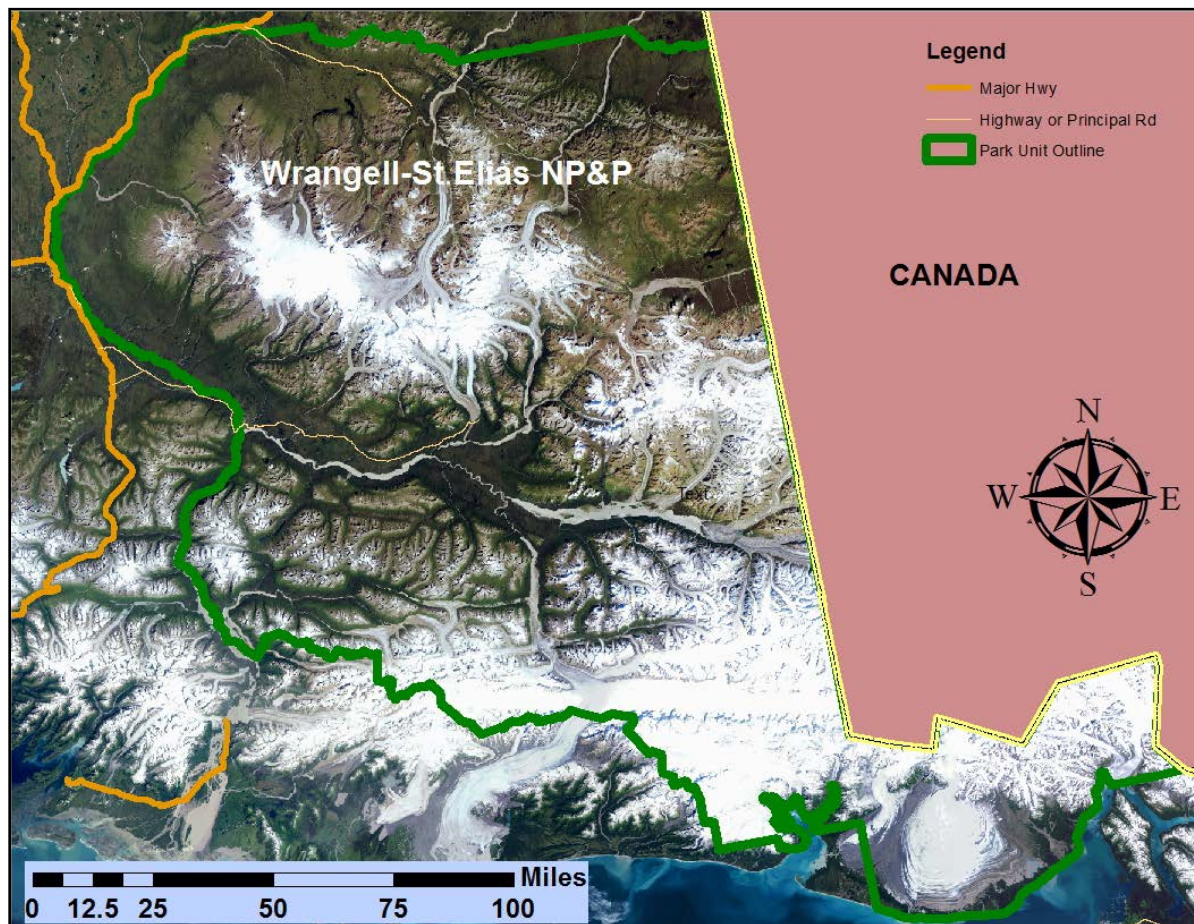


Figure 2. Map of Wrangell-St. Elias National Park and Preserve. Highways and secondary roads are depicted. Note that both roads into the park (the 42-mile Nabesna Road in the north and the 60-mile long McCarthy Road in the central area) are unpaved.

Wrangell-St. Elias spans three climatic zones (coastal, transitional, and continental). Large expanses of open, low-elevation terrain occur within the Copper River basin, a relic of the huge pro-glacial Lake Ahtna, which formed behind an ice dam at the confluence of the Copper and Chitina Rivers during the Pleistocene. The valley floor is now covered with braided river channels and surficial

deposits mixed from alluvium and glacial outwash. Most of the rivers and streams in Wrangell-St. Elias are heavily influenced by glacial activity. The dynamics of water processes in this landscape are controlled in part by the extreme winter weather. Five different types of permafrost occur commonly throughout the park, strongly affecting surface water dynamics. Ice flows and periodic ice jams can cause brief but sometimes catastrophic flooding in low-lying areas. WRST features a diverse fish fauna, including large salmon populations that support commercial, subsistence, and recreational fisheries. The Copper River and its tributaries provide critical migration corridors and spawning and rearing habitat for sockeye, coho, chum, and chinook salmon, as well as steelhead. Other fish species found in park rivers include pink salmon, Dolly Varden, burbot, arctic grayling, cutthroat and rainbow trout, longnose sucker, three species of sculpin, and six species of whitefish.

Denali National Park and Preserve

Denali National Park and Preserve (DENA) is the oldest, best-known, and second most-visited national park in Alaska, and has been designated by UNESCO as an International Biosphere Reserve (Figure 3). DENA spans four ecoregions, including substantial areas of the Tanana-Kuskokwim Lowlands and Alaska Range Transition, along with small areas of the Kuskokwim Mountains in the northwest and Cook Inlet Basin in the south. The park covers some six million acres, of which over two million are designated wilderness. Although dominated by, and best known for, the 20,000-foot-high bulk of Denali (Mt. McKinley), DENA is home to a wide variety of landscapes, ranging from the flat wetlands around Lake Minchumina in the northwest to high-altitude tundra in the Alaska Range to wetter and more temperate areas in the rarely visited southern part of the park. A number of large glacially influenced rivers flow both north and south out of the Alaska Range. There are also numerous smaller clearwater streams that arise in the Alaska Range foothills, the Kantishna Hills, and in the flat northwestern part of the park. Streams in the northwest are more likely to have high levels of dissolved organic carbon and be highly colored. DENA streams and rivers flow into three major river basins. The south side of the Alaska Range is dominated by the Susitna Basin, whereas most streams and rivers on the north side of the range flow into the Tanana River and thence into the Yukon. The far western part of the park includes a small portion of the Kuskokwim basin. Although subsistence and recreational fisheries are less important here than in the other network parks, DENA rivers do support a variety of fish species, including chinook, coho, sockeye, and chum salmon; Dolly Varden; arctic grayling; slimy sculpin; and several whitefish species.

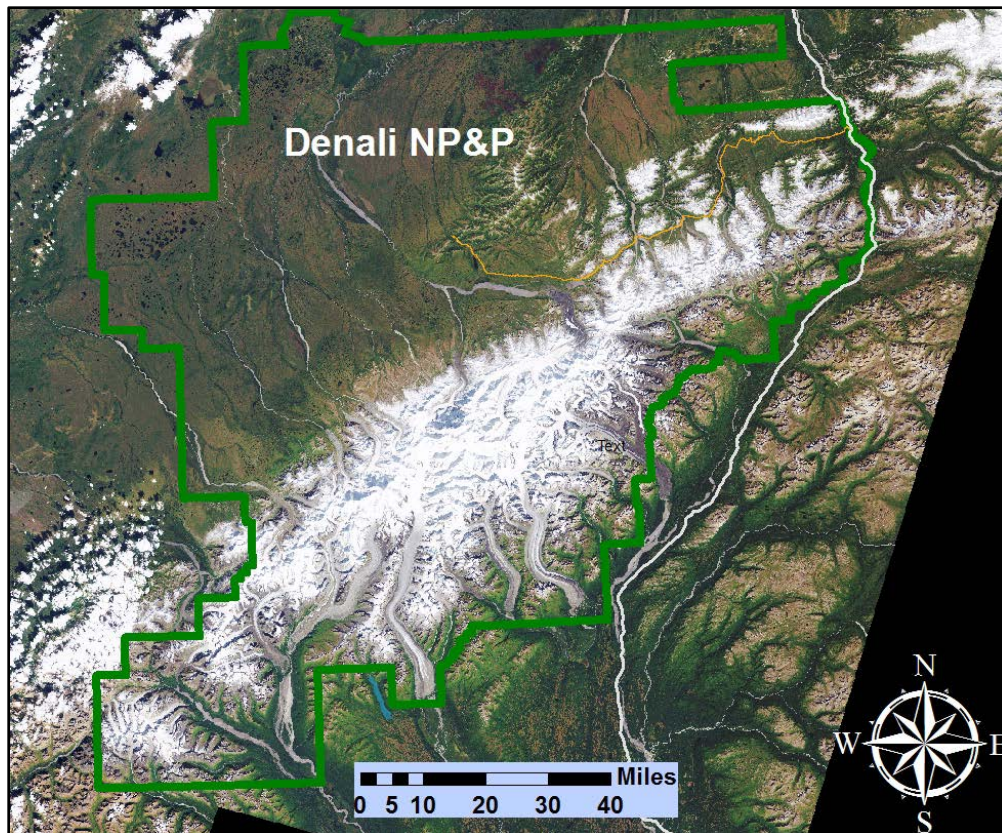


Figure 3. Map of Denali National Park and Preserve. The Parks Highway (gray) is depicted along the eastern border of the park and the 90-mile Denali Park Road (tan) is also shown.

Yukon-Charley Rivers National Preserve

Yukon-Charley Rivers National Preserve (YUCH) flanks over 120 miles of the Yukon River, which at over 2300 miles long is the second longest river in North America (after the Mackenzie), and which drains some 320,000 square miles of Alaska and Canada (Figure 4). YUCH contains the entire basin of the 100-mile-long Charley River (a designated National Wild and Scenic River). Several major tributaries of the Yukon also flow through the preserve, including the Tatonduk, Nation, and Kandik Rivers. YUCH contains 2.5 million acres of remote boreal forest and upland tundra and spans three ecoregions in interior Alaska, the Yukon-Tanana Uplands, the North Ogilvie Uplands, and in the far northwest a small portion of the Yukon-Old Crow Basin (Nowacki et al. 2002). The climate is typical of interior Alaska, with short, warm summers and long, very cold winters. With the exception of the mainstem Yukon, which is turbid from glacial silt inputs upstream (originating in the White River), all of the streams and rivers in YUCH run clear. Seventeen species of fish have been reported to occur in streams and rivers in YUCH, including coho, chinook, and chum salmon (Morrow 1980; Daum 1994). Although YUCH is primarily a transit corridor for chinook salmon headed for spawning grounds in Canada, it has recently been discovered that juvenile chinook from Canada migrate into the preserve to rear in small tributaries (Daum and Flannery 2009).

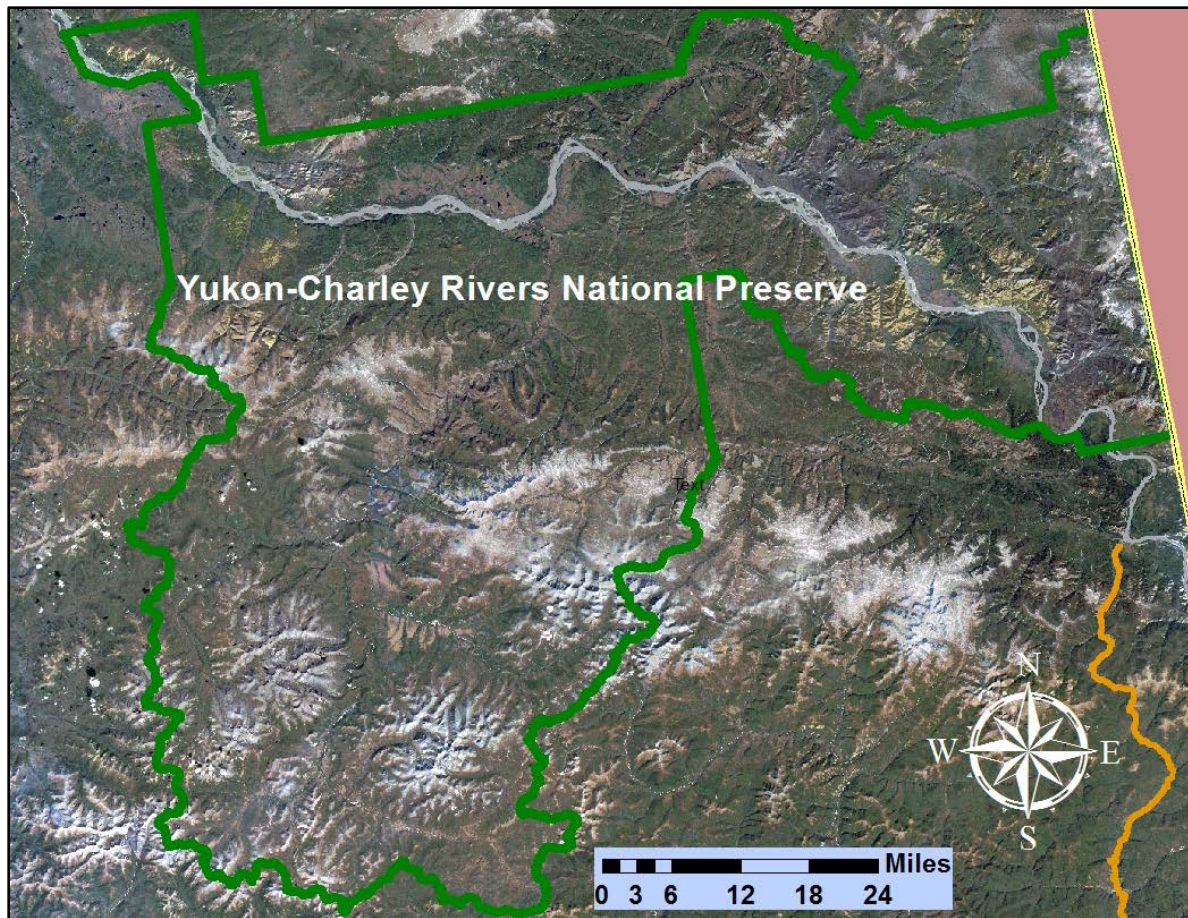


Figure 4. Map of Yukon-Charley Rivers National Preserve. Canada is directly to the east of the preserve. The Taylor Highway, which ends at the Yukon River approximately 12 miles upstream of the preserve boundary, is shown in the lower right corner.

Extant Data

The flowing waters of the CAKN are relatively poorly studied and historical data are scarce. Therefore, a major focus of the CAKN monitoring program is to address this information gap by establishing baseline data on the biological, chemical, and physical characteristics of network streams and rivers. An early example was the freshwater fish inventory conducted in 2003 and 2004, which sampled 48 lakes and 83 streams across the network and substantially increased knowledge of fish species distributions in the three network parks (Markis et al. 2004). Despite 11 years of additional data collection, however, most of the network remains poorly characterized.

Of the three CAKN park units, by far the most is known about the streams and rivers of DENA. This is largely due to two factors: the legacy of mining in the Kantishna area and the status of DENA as a prototype park for the Inventory and Monitoring program. Reasonably extensive, though by no means comprehensive, data have been collected regarding water chemistry (summarized in Edwards and Tranel 1998) and benthic macroinvertebrates (Conn 1998; Milner et al. 2003) from streams in DENA, although these are largely confined to sites along the road corridor. Little or no data regarding benthic diatom communities had been collected prior to the initiation of the CAKN

program. There are no active stream gages in DENA and only one operated in the park historically, on the Teklanika River, so streamflow data are essentially nonexistent. The distribution of fish species within DENA is also poorly documented, with relatively few extant data (but see Miller 1981; Markis et al. 2004).

Less is known about flowing water in WRST, although the United States Geological Survey (USGS) has been collecting data in some areas of the park for decades. USGS gaging stations have been operated in and around the park for at least 50 years; however, few of them (6 of 17) have been located within the boundaries, and the data records tend to be relatively short. The longest record is from 1950–1990, from a gage that was located just outside the boundary of the park on the Copper River. Most other flow records are three to six years in length and range from the early 1900s to the late 1970s. There are currently no active gaging stations within WRST. Similarly, historical water chemistry data are only available for a small number of streams in WRST. Data regarding fish populations in WRST are largely confined to documenting escapement of anadromous salmon in the Copper River, including both king salmon and the world-famous Copper River sockeye. Far less is known about the distribution and abundance of other fish species; resident species are particularly poorly understood. Very little information regarding macroinvertebrate and benthic diatom communities in WRST had been collected prior to the initiation of data collection by the CAKN.

Relatively little is known about the flowing waters of YUCH, although discharge and water chemistry have been monitored for the mainstem Yukon River upstream of YUCH at Eagle since 1950. The USGS has conducted some analyses of the water chemistry of the Yukon Basin in recent years (e.g., Dornblaser and Streigel 2007; Streigel et al. 2007). Some discharge and water chemistry data also exist for the Nation and Kandik Rivers; however, in general, there have been few studies of either the physicochemical or biological attributes of any streams and rivers in the preserve. In the only historical study of lotic macroinvertebrates in YUCH, 47 taxa were identified (Daum 1994).

Rationale for Selection of Stream-related Vital Signs

The original CAKN Monitoring Plan listed four Vital Signs specific to flowing water. These were (1) disturbance: stream flood frequency and discharge, (2) river/stream flow, (3) macroinvertebrates, and (4) the distribution and abundance of freshwater fish (MacCluskie and Oakley 2005). Contained within these Vital Signs were several related objectives, which included (1) determine the composition and spatial distribution of aquatic organisms within rivers/streams selected for sampling, (2) detect changes in indices of stream productivity, (3) determine long-term trends in flood frequency and discharge of selected rivers and streams in the network, and (4) determine temporal and annual long-term trends in discharge of selected rivers and streams in the network. Based upon pilot studies conducted by the network since 2005, along with a reassessment of network capabilities and priorities, these Vital Signs have been modified. The new Vital Signs are (1) hydrologic regime, (2) composition and distribution of aquatic communities, and (3) chemical and biological measures of water quality.

Hydrologic Regime

The timing, magnitude, frequency, and duration of high and low flows are fundamental drivers in determining the structure and function of lotic and riparian ecosystems (e.g., Poff et al. 1997; Allan 2000). In general, changes in the hydrologic regime of streams and rivers have the potential to alter both aquatic and riparian ecosystems (Poff et al. 1997; Rood et al. 2005). Changes in hydrologic regime also influence patterns of erosion, transport, and deposition of alluvial sediments and thus can alter channel and floodplain characteristics, including fish and vegetation habitat. Climate change is expected to alter stream hydrology in many areas (Poff 2002), which will affect all aspects of fluvial ecosystem function (Firth and Fisher 1992; Meyer et al. 1999) ranging from food web interactions (Power et al. 1995) to nutrient cycling. Changes in baseflow characteristics (generally quantified as the ratio of annual seven-day minimum flow to annual mean flow) may affect the following: balance of competitive and stress-tolerant organisms; creation of sites for plant colonization; structuring of aquatic ecosystems by abiotic vs. biotic factors; structuring of river channel morphology and physical habitat conditions; soil moisture stress in plants; dehydration in animals; anaerobic stress in plants; volume of nutrient exchanges between rivers and floodplains; duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments; distribution of plant communities in lakes, ponds, and floodplains; duration of high flows for waste disposal; and aeration of spawning beds in channel sediments. Changes in the timing of annual extreme water conditions (such as spring snowmelt) may affect the life cycles of organisms, predictability and hence avoidability of stress for organisms, access to special habitats during reproduction or to avoid predation, spawning or outmigration cues for migratory fish, evolution of life history strategies, and behavioral cues. In the CAKN, melting permafrost, receding glaciers, and changes in the timing and magnitude of winter and summer precipitation can be expected to affect the hydrologic regime of most aquatic systems. Changes in soil water holding capacity and infiltration rates, along with changes in connectivity between surface and groundwater, as a result of permafrost degradation will also have major impacts on the hydrographs of streams in permafrost-dominated areas.

There are currently no active stream gages on any rivers or streams within CAKN parks, making monitoring changes in flow regime at the network scale challenging. To address this challenge, we will use data from existing gages adjacent to the parks and will also collect qualitative flow data from streams within the parks. We will use data collected by the USGS at the existing Yukon River gaging station at Eagle, just upstream of YUCH. This gage has been active since 1950, providing a powerful dataset for assessing long-term changes in hydrologic regime. We will also use data collected by the U.S. Fish and Wildlife Service (USFWS) at a recently established gaging station on the Nabesna River in Tetlin NWR, just downstream of WRST. The CAKN is collaborating with USFWS to keep this gage operating past its original five-year lifespan. The CAKN Stream Monitoring Program is responsible for station maintenance and field data collection, whereas the USFWS is responsible for data management, QA/QC, analysis, and reporting. The station has been reporting real-time stage and discharge since 2012.

We will collect qualitative flow information for the stream monitoring program as part of the regular sampling procedure during each site visit. We will record a qualitative assessment of the stream stage (e.g., dry, baseflow, moderate, etc.), as well as measuring instantaneous discharge as time permits.

Composition of Aquatic Communities (Invertebrates, Diatoms and Fish)

Invertebrates and diatoms are central to aquatic food webs, and constitute a substantial proportion of the biodiversity found in streams and rivers, in terms of not only species diversity but also functional diversity and abundance. Through 2015, the CAKN stream monitoring program has documented 203 unique invertebrate taxa and 440 species of benthic diatoms in network streams (Simmons, unpublished data). As such, these communities represent a substantial proportion of all species diversity that inhabits these parks. Most of these species had not been documented to occur in the parks prior to the initiation of the CAKN Stream Monitoring Program. Establishing a complete taxa list for and mapping the distribution of invertebrates and diatoms in the CAKN is therefore an important part of understanding the extant biodiversity of this landscape. Similarly, documenting changes in the structure of these communities will help us to more fully understand the effects of climate change on aquatic ecosystems.

In contrast, total documented fish species richness in the CAKN is less than 30 species (Markis et al. 2004); however, freshwater fish are important components of these aquatic communities. Anadromous fish are especially important, occurring in all three parks, where they migrate, spawn, and rear young. Although a number of species in the CAKN are known to be anadromous, including several species of whitefish and lamprey, Dolly Varden, and rainbow trout, the five species of salmon are by far the most numerous. Salmon, by delivering marine-derived nutrients into the freshwater and terrestrial environment (e.g., Cedarholm et al. 1999; Gende et al. 2002), are considered keystone aquatic species in the network, although the specific role of salmon in each park is somewhat different (YUCH, mainly a migration corridor; DENA, late fall spawning chum salmon provide critical subsidies to wildlife; WRST, critical for commercial and subsistence fisheries and ecosystem food webs).

In addition to their innate importance to network aquatic ecosystems, each of these organisms can serve as sensitive indicators of ecosystem status and ecosystem change. With the exception of some

anadromous fishes, they are present in these systems continuously and therefore integrate the effects of episodic or low-level stressors that may not be detectable by conventional sampling. In addition, they are sensitive to the synergistic effects of multiple stressors and to stressors that are not assayed for. Invertebrates in particular have long been recognized as effective tools for assessing aquatic ecosystem condition. In addition to being known to respond sensitively to environmental stress, they are ubiquitous in flowing waters, are generally diverse and abundant where they are found, are relatively sedentary (and hence responsive to local conditions), and are relatively inexpensive to collect and analyze (Barbour et al. 1999).

Each of these communities responds to environmental changes at different spatial and temporal scales. Hence, by monitoring the condition of all three, the CAKN could maximize the range of stressors whose impacts on lotic ecosystems can be detected (Carlisle et al. 2008). However, development and maintenance of a robust freshwater fish monitoring program for CAKN parks is currently not feasible, given the fiscal constraints the program operates under. We intend to periodically re-evaluate whether the level of resources we have available is sufficient to add monitoring of fish communities to the program in the future. Nevertheless, monitoring the condition of both invertebrate and diatom communities will provide a more comprehensive picture of ecosystem status than relying on a single community.

Chemical and Biological Water Quality

Water resources were identified as a central focus of the CAKN monitoring program very early in its development (MacCluskie and Oakley 2005). A critical determinant of the overall condition of these resources is water quality. Although the aquatic ecosystems in the network are in general relatively pristine, especially in comparison to those in parks in the Lower 48 states, they have been subject to varying degrees of alteration from both global and local effects of human activity, effects that are expected to increase in the near future. State and federal laws and regulations require reporting on water quality in national parks. Therefore, monitoring water quality is the most important priority of the stream and river monitoring program. Understanding water quality, and how it may be changing both at individual sites as well as across the landscape, will provide park managers with an important tool in responding to ongoing effects of both local and global industrialization on park ecosystems.

We will focus on two approaches to evaluating water quality. The first will be to collect a comprehensive suite of water chemistry data. As shown in Table 3, the concentrations of selected solutes can be used to assess not only water quality *sensu strictu* but also various aspects of stream ecosystem function. However, although water chemistry constitutes an important part of the water quality of Alaska streams, particularly in areas that are subject to the effects of mining and urban runoff, it is only part of the picture. Section 101 of the Clean Water Act (formally the Water Pollution Control Act Amendments of 1972 (Pub. L. 92- 500)) states that the purpose of the act is to “restore and maintain the chemical, physical and biological integrity of the Nation’s waters.” In other words, water quality is concerned with the overall state of aquatic ecosystems. In general the chemical water quality characteristics of a stream, as typically measured, tell us relatively little about its biological (or physical) condition. Similarly, attainment of chemical water quality standards does not ensure a healthy biological condition (Yoder and Rankin 1998). There are a number of reasons

for this, but three important ones are (1) the extreme temporal variability and flow dependence of solute transport in streams, (2) the difficulty of measuring all of the chemical constituents with the potential to affect biological condition, and (3) the pervasiveness of degradation that is not related to chemical measures of water quality (including habitat degradation, changes in sediment budgets, changes in riparian vegetation structure, the presence of invasive species, etc.). Consequently, the use of biological indicators of water quality has become a key component of water quality assessment programs around the globe and will be the focus of the CAKN water quality monitoring program.

Table 3. Water chemistry parameters and the rationale for collecting them.

Water Chemistry Parameter	Rationale for Sampling
Instantaneous temperature*	Required WRD core parameter
Continuous temperature	Affects habitat suitability, life history for aquatic organisms
Dissolved oxygen (DO)*	Required WRD core parameter, primary productivity and distribution of biota
pH*	Required WRD core parameter, affects habitat suitability for aquatic organisms
Specific conductivity*	Required WRD core parameter. Indicator of geology, affects distribution of biota, often correlated with mean annual temperature and presence of pollutants
Total nitrogen	Trophic state, nutrient dynamics
Total nitrate/nitrite nitrogen	Biogeochemistry, nutrient dynamics
Ammonia-nitrogen	Biogeochemistry, nutrient limitation
Dissolved organic nitrogen	Biogeochemistry, nutrient dynamics
Total phosphorus	Trophic state, biogeochemistry, nutrient dynamics
Orthophosphate	Measure of biologically available phosphorus, trophic state, biogeochemistry, nutrient dynamics
Apparent color	Light availability, carbon metabolism
Silica	Required for diatom growth
Alkalinity	Buffering capacity of water – changes have been related to permafrost degradation
Calcium and magnesium	Measure of water hardness
Base cations/anions	Measure of weathering rates and indication of retrogressive thaw slumps
Dissolved organic carbon (DOC)	Measure of organic matter contributions from terrestrial ecosystems, indication of permafrost degradation, correlated with bioavailable Hg

*represent core water quality parameters required by the NPS Water Resources Division (WRD)

The rationale for using biological indicators to assess water quality can be summarized as follows: (1) the biological community is always present in the stream (or lake, or wetland), therefore it integrates the effects of temporally variable stressors; (2) the biological community responds to all relevant stressors, whether chemical, physical, or biological and whether or not they are measured or even known; and (3) the biological community responds to the cumulative and synergistic effects of multiple stressors that are difficult to quantify directly. In essence, the biological community acts as an integrator of the effects of all stressors potentially impacting a stream for stressors that may be

chemical, physical, or biological in origin. Hence, of the three aspects of water quality defined in the Clean Water Act, it is measures of biological integrity that should best reflect the overall ecological condition of a stream. This is important, because the Clean Water Act requires a fundamentally ecological approach to water quality (“chemical, physical and biological integrity”).

As this ecological approach becomes increasingly common, it has been reflected in widespread references to assessing the biological or ecological integrity of waterbodies, rather than their “water quality” per se. Karr (1981) and Hughes et al. (1982) originally developed a working framework for assessing biological integrity: (1) establishing base, or reference, conditions within ecoregions to represent the expected conditions at unimpaired sites; (2) the use of multiple reference sites to establish those reference conditions; and (3) a method for comparing baseline (reference) conditions with potentially impacted conditions to determine the relative health of a site (i.e., its biological integrity). This is the approach the CAKN monitoring program will use to assess water quality in network streams.

In principle there are a number of aspects of biological communities or ecosystems that could be evaluated to determine biological condition, including species composition, species relative abundance, species diversity, food-web structure, productivity, decomposition, and nutrient cycling. In practice, however, nearly all ecological assessment methods focus on some aspect of assemblage structure and operate under the assumption that changes in assemblage structure are correlated with changes in overall ecosystem health or integrity. The earliest and still most widely used of these methods is known as the Index of Biological Integrity (IBI, Karr 1981). Originally designed for fish, the approach essentially relies on comparing the values of various measures of assemblage structure between reference sites (relatively unimpacted) and test sites (potentially impacted). The measures, or metrics, are generally chosen because (1) their responses to anthropogenic stress can be predicted based on ecological principles (e.g., native species richness will decrease, species dominance will increase, number of intolerant species will decrease, etc.); and (2) their responses along a gradient of known condition are of sufficient magnitude to allow reference and impaired sites to be distinguished reliably. Individual measures are then standardized (rescaled) and their values combined to generate what is known as a multimetric index. The value of this index provides a measure of biological integrity. Impairment thresholds can be (and are) defined by comparison to the distribution of IBI scores from reference sites (e.g., a common impairment threshold is the 25th percentile of reference site scores). Currently every state in the U.S. has developed some version of the IBI approach for the bioassessment of water quality. IBI-based bioassessment is also used by tribal governments and federal agencies and is common internationally. IBIs are used in EPA’s ongoing nationwide assessments of water quality, the National Aquatic Resource Surveys, which is a rotating program that assesses streams and rivers, great rivers, lakes, wetlands, and coastal resources (see e.g., USEPA 2006).

A similar assemblage-based bioassessment approach has been developed in parallel with the IBI. This methodology, known as RIVPACS (River InVertebrate Prediction and Classification System, Wright et al. 1984; Moss et al. 1987), uses natural environmental gradients to predict the native species composition of benthic invertebrates. Very briefly, environmental variables that are not

expected to change substantially in response to anthropogenic stress (e.g., elevation, slope) are used to predict the number of native taxa expected to be captured at a given site (called E), if the site is unimpaired. The ratio of the observed number (called O) of the expected taxa that are actually captured to this expected number, or O/E, represents the degree to which the native fauna is intact and hence provides a measure of biological integrity at that site (Clarke et al. 1996). In other words, an O/E score of 0.5 indicates that only 50% of the expected native taxa are still present. The assumption is that the loss of native taxa is reflective of overall ecosystem condition. The predictions are developed using only data collected from unimpaired reference sites, and so do not depend on calibration against a gradient of known condition. This helps the RIVPACS method to avoid some of the circular logic that is inherent in the IBI approach (“a gradient of known condition”), though not all, as objectively defining what is or is not a reference site has proven challenging.

RIVPACS was developed as, and remains, the primary assessment methodology for the national water quality program in Great Britain (Clarke et al. 2003). The RIVPACS methodology, which is referred to generically as a “predictive modeling” or “O/E” approach, has since been applied in a variety of monitoring contexts. The vast majority of these applications continue to focus on benthic macroinvertebrates, although O/E models have been successfully applied to fish, amphibians, and diatoms as well as other organisms (e.g., Hawkins 2006; Carlisle et al. 2008). RIVPACS-type predictive modeling is now an integral part of the EPA national water quality assessment program (USEPA 2006), and is already implemented or in development for many individual states as well (e.g., Hargett et al. 2007; Hubler 2008). RIVPACS-type bioassessments are also used by the national water quality monitoring programs of Australia (e.g., Smith et al. 1999) and Canada (Reynoldson et al. 1995), as well as by a number of other countries (e.g., Sweden – Johnson and Sandin 2001; Czech Republic – Kokeš et al. 2006; Spain – Poquet et al. 2008; and New Zealand – Joy and Death 2003). The technical aspects of the various methodologies used by these countries differ somewhat, but the underlying philosophy remains the same.

Both of these approaches to bioassessment have strengths and weaknesses; on the whole, however, the RIVPACS approach is preferable for Alaska national parks. Although both IBI and RIVPACS tend to produce similar results in large-scale assessments (e.g., USEPA 2006), in many cases the RIVPACS models are more sensitive to low-to-moderate levels of impairment, of the type we would expect to encounter most often in the CAKN. However, perhaps the more important advantage for these parks, where we expect to see infrequent and low levels of degradation, is that RIVPACS models do not require calibration against a known gradient of impairment; they are developed using only data from reference (unimpaired) sites. For these reasons, the CAKN monitoring program is focusing on the development and implementation of RIVPACS-type models for the bioassessment of water quality in network streams. These models will, in principle, allow us to evaluate the biological condition of individual streams of interest to park managers, as well as to determine the average condition of all streams in an individual park or in the network as a whole.

An emerging challenge for water quality assessment worldwide is the so-called stationarity problem (Milly et al. 2008). Essentially, the ongoing effects of climate change on aquatic ecosystems are likely leading to a changing baseline, which could result in detecting impairment or a change in

condition where none exists, or vice versa. Typically, water quality conditions at sites of interest are assessed by comparing them to conditions at appropriate sets of reference sites. Conditions at reference sites are generally established using data collected over a relatively short time (one to several years); this constitutes the baseline against which conditions at test sites are compared. Until recently, the assumption has been that there were no long-term directional shifts in the baseline, so these comparisons remained valid over time. However, it is becoming clear that this assumption is not likely to hold in the future, if indeed it does at present. Given the rapidity of observed change in the arctic and subarctic, dealing with the stationarity problem will be challenging.

However, we can also take advantage of this phenomenon to document the effects of ongoing climate change on aquatic communities. RIVPACS models are designed to detect changes in aquatic community structure away from expectations set by modeling the distribution of organisms among a set of reference sites. Generally those reference data are collected over a limited number of years, and so establish a baseline against which future changes in community structure can be assessed, both at the same reference sites used to construct the model, as well as at other sites in the network.

Physical Habitat

Although monitoring of geomorphology is not specifically delineated as a Vital Sign, we will collect an extensive set of physical habitat measurements as part of field data collection. Many of these measurements could be used as predictor variables in the development of predictive models for invertebrate and diatom community composition. In general, given the survey design and method of field collection, the habitat data we will collect are likely not sufficient to serve as the basis for the detection of geomorphic change (e.g., Kaufmann et al. 1999; Archer et al. 2004; Whitacre et al. 2007). However, they can in themselves serve as important indicators of habitat quality for fish and other aquatic organisms (Table 4), and could in principle be used to assess qualitative changes. The size distribution of benthic sediments is an indicator of the quality and extent of spawning habitat for salmonids, as most species depend on restricted size classes. Pool frequency and average pool depth are important indicators of habitat quality for many stages/functions of salmonid (and other fish) life histories (e.g., Beechie and Sibley 1997). These can be quantified using measures of residual pool depth, which eliminate the effects of discharge variation on the definition and characterization of pools (Kaufmann et al. 1999). Riparian canopy cover serves as source of large and small wood and important terrestrial subsidies of insects (e.g., Nakano and Murakami 2001) as well as providing shading to maintain cool temperatures. Canopy cover is also roughly (inversely) correlated with potential instream primary productivity.

Table 4. Examples of ecological indicators that can be derived from habitat data that will be collected as part of the CAKN stream monitoring program.

Metric	Interpretation
Substrate d50	Measure of grain size distribution
Residual pool depth	Measure of fish habitat availability
Mean % canopy cover	Surrogate for solar energy input
Percent pool	Measure of habitat distribution
Mean depth	Measure of active channel size
Mean width	Measure of active channel size
Width/depth ratio	Measure of channel shape
CV of depth	Measure of habitat complexity

Although monitoring channel change is not currently a formal part of the stream monitoring program, ongoing advances in remote sensing offer the possibility of quantitatively monitoring channel change with any of a variety of airborne or satellite-based methods (Lane and Carbonneau 2007). A significant advantage of remote sensing approaches is that they facilitate monitoring channel change at an ecologically relevant scale—the reach or segment scale as opposed to a single channel cross section. These methods include photogrammetry, multispectral imagery, and laser-based approaches (Lane and Carbonneau 2007). Among the most promising may be green LiDAR, which can return data from the bottom of the stream as well as the surface, allowing detailed and accurate channel mapping under all flow conditions (Hilldale and Raff 2007; Kinzel et al. 2007). Limitations of all optical remote sensing approaches include interference from riparian vegetation, severe turbulence, and turbidity. We will continue to assess the feasibility of incorporating remote sensing of channel form into the monitoring program in the future.

Link to National and Regional Strategies

At present, a number of state and federal agencies in Alaska are engaged in varying degrees of stream monitoring. Aside from the National Park Service, these agencies include the Alaska Department of Environmental Conservation (ADEC), the Alaska Department of Fish and Game (ADF&G), the Alaska Department of Natural Resources (ADNR), the Bureau of Land Management (BLM), the U.S. Forest Service, the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service (USFWS) and the U.S. Geological Survey (USGS). The Aquatic Ecology Program at the University of Alaska Anchorage is also an important player in stream monitoring activity in Alaska and has worked with both ADEC and USFWS to develop stream monitoring and assessment methods across the state (Bogan et al. 2012; Rinella and Bogan 2008; Rinella and Bogan 2007; Jessup et al. 2005; Rinella et al. 2005). Monitoring activities are coordinated to some degree amongst these agencies through the Interagency Hydrology Committee for Alaska, in which the Central Alaska Network is an active participant. With the exception of the ADEC, each of these agencies' programs is in general narrowly focused, although the USFWS is in the early stages of developing broad-scale aquatic monitoring programs for Alaska refuges, and the BLM has recently begun to monitor aquatic resources across interior Alaska through their Inventory, Monitoring, and Assessment Program.

ADEC currently reports on water quality in the state's rivers and streams in a biennial report (e.g., ADEC 2010). Unlike most of the Lower 48 states, however, Alaska has neither a comprehensive statewide water quality monitoring program nor an active biological assessment program. Although ADEC expects that 99.9% of Alaska waters meet water quality standards for all designated uses, the lack of a statistically robust assessment program means that this expectation cannot presently be tested. For the vast majority of Alaska waters, sufficient water quality data do not exist to assess whether water quality standards are being met (ADEC 2005). The ADEC is still developing a comprehensive assessment and monitoring strategy for water quality. Although ADEC recognizes the importance of narrative or numeric biological criteria for assessing water quality (ADEC 2005), at present there are no plans to implement a biological assessment program beyond a series of relatively small-scale pilot studies that are being funded by the EPA. Currently, the EPA has funded several spatially limited studies of rivers and streams in Alaska as part of the National Rivers and Streams Assessment (NRSA). These studies collect the full suite of NRSA data using the same EPA protocol on which the CAKN stream monitoring protocols are based. These studies fall under the ADEC's Alaska Monitoring and Assessment Program (AKMAP), which is responsible for monitoring coastal and freshwater systems in Alaska. To date, these studies have included a survey of wadeable streams in the Tanana Basin in 2004–2005 (Rinella and Bogan 2008), a survey of the mainstem of the Tanana River in 2006 (Moran 2007), a survey of the mainstem of the Yukon River in 2009 (Lomax et al. 2012), and a survey of wadeable streams on the North Slope in 2015–2016.

The general lack of an existing structure for stream monitoring and biological assessment in Alaska is both a challenge, because the CAKN program cannot simply “plug in” to ongoing monitoring efforts, and an opportunity, because it will allow us to work with other agencies to build an infrastructure from the ground up. Because the CAKN program is based on the same EPA NRSA protocols and standards as the ADEC AKMAP program, the data collected by both programs are

compatible and easily combined. Currently, the CAKN shares water quality data with ADEC on an informal basis. CAKN water quality data are also available to the ADEC through the EPA's STORET database, and vice versa. Active discussions are ongoing regarding how the CAKN and the ADEC might cooperate on development of biological assessment methods that meet the needs of both organizations. The current iteration of the CAKN RIVPACS biological assessment tool relies solely on data collected by CAKN; however, we are now in the process of developing an updated RIVPACS model that will incorporate data collected by ADEC in and near network parks. Similarly, the CAKN is in active discussions with scientists from the U.S. Geological Survey, the Bureau of Land Management, and the University of Alaska Anchorage regarding standardization of water quality and biological assessment data collection and analysis between the CAKN and other federal agency monitoring programs, as well as the development of regional-scale or statewide biological assessment tools for monitoring water quality.

Survey Design

Rationale for Survey Design Selection

We have selected a multipanel survey design focused on wadeable streams that incorporates a large set of probabilistically selected synoptic sites that will be sampled on a long rotation schedule, along with a small number of sentinel sites that will be sampled annually. The rationale for this design is as follows. In principle there are a number of survey designs that could be implemented in a stream monitoring program. One goal of the CAKN program is to be able to make statements about status and trends at the network scale.

Generally a probabilistic survey design is considered to be preferable for surveys of this type, where maximal inference to unsampled sites is a goal. Probabilistic surveys rely on each site in the population having a positive, though not necessarily equal, chance of being selected as part of the sample, and generally allow the use of standard statistical methods to estimate bias and variances. Inference in study designs of this type is design-based. The Environmental Protection Agency (EPA) has developed a probabilistic survey design intended specifically for large-scale environmental monitoring programs (Herlihy et al. 2000; Stevens and Olsen 2004). It is particularly well suited to monitoring stream and river resources, as it allows the selection of discrete sampling locations from complex linear networks. This design, known as the Generalized Random Tessellation Stratified (GRTS) design, generates a spatially balanced, probabilistic sample that can be stratified and unequally weighted, which will allow us to account for differences in the cost of access and in stream size across the network (Overton and Stehman 1993, Stevens and Olsen 2004). The GRTS design is used by the EPA in state, regional, and national surveys of water quality and aquatic ecosystems (Herlihy et al. 2000; USEPA 2006), and by other state and federal agencies as well. A number of NPS Inventory and Monitoring Networks also employ GRTS designs for their monitoring programs (e.g., Magdalene et al. 2008; Dinger et al. 2011; Schweiger et al. 2015). For these reasons, we determined that a GRTS design is the most appropriate survey design for monitoring status and trends in fluvial ecosystems in the CAKN with maximal spatial inference. We refer to the probabilistically selected sites as “synoptic” sites.

There are four components of variance that are important for evaluating the power of these designs to detect regional trends: site-site, year, site-year interaction, and residual (Urquhart et al. 1998; Larsen et al. 2001; Larsen et al. 2004). Site-to-site variation in metric value(s) represents persistent differences among stream reaches in a region (e.g., gradient, elevation, catchment area). There is also coherent yearly variation in metric values across all reaches in a region in response to regional-scale forcings such as climate. Site-year interaction indicates independent, desynchronized yearly variation among all reaches in a region resulting from local-scale influences. Finally, residual variation represents the remaining variation and consists primarily of short-term variation during the temporal window when measurements are made, measurement error, crew-to-crew variation in protocol application, etc. Site-to-site variability tends to swamp others sources of variance and can substantially reduce sensitivity to trends (Urquhart et al. 1998). However, explicitly incorporating revisits can effectively eliminate this effect and greatly increase sensitivity to trends (Urquhart et al. 1998; Urquhart and Kincaid 1999), assuming reasonable coherence in regional response (i.e., that

site-year variability is not large). For this reason, we are using a panel rotation approach, in which sites are revisited periodically according to a master schedule.

Maintaining a strict revisit schedule for the synoptic sites in a large remote landscape like the CAKN will be challenging, given the cost of accessing sites and logistical constraints imposed by weather and other considerations. Deviations from the revisit schedule will complicate trend detection and accurate variance estimation. In addition, given the large number of sites that must be sampled to adequately represent the variety of stream ecosystems in this large and complex landscape, the revisit interval is of necessity fairly long. This will also affect our ability to detect trends; however, we are incorporating a second survey approach to ameliorate this issue. We consider the benefits of a large-scale landscape approach to sampling to outweigh these potential drawbacks.

The use of a small number of accessible sentinel sites that are sampled repeatedly will aid in reducing the effects of site-to-site variability on trend detection. Annual visitation will maximize our ability to detect trends at these sites, although inference to unsampled sites will be limited. Therefore, in addition to the synoptic site panels, we have established a set of sentinel sites that are sampled annually. Sentinel sites have been selected primarily according to ease of access but are distributed as much as possible among representative stream types. The typology is based on expert opinion, and relies on broad physical attributes (size, geology, glacial influence, geomorphology, elevation, etc.). To the extent possible, these sites will be visited more than once per year, allowing the seasonal component of variance in the values of ecological metrics to be estimated and accounted for (e.g., Larsen *et al.* 2004). The sentinel sites for DENA and WRST are listed in Table 5. At present we have not yet identified any logistically feasible sentinel sites in YUCH (i.e. sites we can reliably access every year).

Table 5. List of annually sampled sentinel sites.

Stream name	Park unit	Access	Description
Lake Creek	DENA	Hike from Park Road	Low gradient, lake outlet
Igloo Creek	DENA	Hike from Park Road	Forested, moderate gradient
Sanctuary River	DENA	Hike from Park Road	Large, open forest, glacial influence
Tattler Creek	DENA	Hike from Park Road	Small, high gradient, open forest
E. F. Toklat River	DENA	Hike from Park Road	Large, braided, glacial
Coal Creek	DENA	Hike from Park Road	Moderate gradient, scrub tundra
Little Stony Creek	DENA	Hike from Park Road	Small, high elevation, tundra
Moose Creek	DENA	Hike from Park Road	Large, low gradient, forested
Jack Creek	WRST	Hike from Nabesna Road	Large, low gradient, forested
Rock Creek	WRST	Hike from Nabesna Road	Small, flashy, forested
Chalk Creek	WRST	Hike from Nabesna Road	Medium size, lake-fed, forested
Paco Creek	WRST	Hike from Nabesna Road	Narrow, low-gradient, tussock tundra
Rufus Creek	WRST	Hike from Nabesna Road	Medium size, groundwater dominated
Gilahina River	WRST	Hike from McCarthy Road	Large, moderate gradient, forested

Finally, one potential drawback of GRTS and other probabilistic survey designs is that they do not always capture the full range of ecological gradients present in a population. This is particularly so in a landscape as large and ecologically complex as the CAKN. Failure to adequately represent these ecological gradients in a sample can complicate the development of robust models (Jay Ver Hoef, National Oceanic and Atmospheric Administration, pers. comm.). For this reason, we will also select “judgment” sites as necessary to increase representation of ecological gradients in the data set. Inference to unsampled sites from data collected at these sites will also be limited. However, Bayesian hierarchical models can be used to combine data from probabilistic and nonprobabilistic surveys. We will therefore use Bayesian methods to facilitate the synthesis of data collected from synoptic, sentinel, and judgment sites. This should allow us to combine sensitivity for trends with spatial inference and provide a powerful methodology for detecting trends at a landscape scale while providing the range of data necessary to construct robust predictive and explanatory models.

Stream Population to be Sampled

Due to limited resources and safety concerns, it is unlikely that we will be able to sample large rivers that cannot be waded safely. Hence, the target population for the program is all wadeable streams in the three park units, and inference will be limited to those systems. We will continue to evaluate potential approaches to monitoring large river ecosystems, which are numerous and important in the network. Although a number of large river sampling protocols have been developed (e.g., Angradi 2006; Magdalene et al. 2008), none are currently feasible to implement at the network scale given the resources of the program. The exception to this rule is the hydrology monitoring station on the Nabesna River, where we will use a jetboat to conduct discharge measurements and water quality data collection. In general, first through third order streams are nearly always wadeable, although glacially influenced streams and low-gradient streams in permafrost-dominated basins may not be safe to sample even when they are first order. A substantial subset of data can be collected from many nonwadeable streams by modifying certain aspects of the field methods (SOP 8: Field Methods). The main modification is to designate the area to be sampled as that portion of the stream extended out from the bank to the limit of safe wadeability. Transects for collection of macroinvertebrates and diatoms can then be established as detailed in SOP 8: Field Methods. Intermittent streams are not typically part of the target population for stream monitoring programs (e.g., USEPA 2013a). However, the CAKN monitoring program will retain intermittent streams in the target population. The rationale for this is that we expect climate change to alter hydrologic regimes in many CAKN streams, resulting in the conversion of intermittent flow to perennial flow, particularly in areas dominated by permafrost. In order to capture this important hydrologic change on the landscape, streams that are dry when visited will be documented and retained in the sampling schedule for future revisits.

Stream Selection

The synoptic sites for each park were selected using the *spsurvey* package (Kincaid 2008) in the R statistical software environment (R Core Team 2016), which uses the GRTS algorithm to define a spatially balanced, probabilistic sample. For each park, the sample was both stratified by accessibility and unequally weighted by stream order. The idea behind stratification is that, at least in principle, accessible sites will tend to be less expensive to sample; thus, monitoring at these sites will be more

sustainable over the long term. By comparing data from accessible and inaccessible sites, it should be possible to determine how comparable the two strata are, which will allow us to estimate whether trends identified at accessible sites are representative of the larger sample should it become necessary to reduce our sampling effort at synoptic sites, restricting it to only the accessible stratum. Accessible sites were defined as being located in a one-mile buffer around roads, trails, airstrips, or floatplane lakes. All other sites were defined as inaccessible. The sample was unequally weighted to preferentially select sites located on second and third order stream segments over higher-order streams in order to maximize the probability that selected sites would be wadeable. The total number of synoptic sample sites varies by park, in approximate relation to the total unglaciated area in each. For WRST, the target sample is 60 sites. For DENA, the target sample is 30 sites, and for YUCH the target sample is 20 sites. The edited GRTS site lists are provided in SOP 2: Sampling Design and Site Selection.

GRTS samples are designed to be sampled in strict order moving down a list. If a particular site cannot be sampled, it is simply eliminated from the target population and the next site on the list is sampled. In the National Rivers and Streams Assessment, this “next” site is restricted to fall within a range of Strahler stream orders determined by the stream order of the skipped site (USEPA 2007). However, this approach is unrealistic for the Central Alaska Network, where consecutive sites may be hundreds of miles apart and require helicopter access as well. Accordingly, the CAKN has adopted a modified approach that maximizes the cost-effectiveness of data collection by de-emphasizing the ordering of the sites and instead emphasizing logistics. In practice, this means that in any given year the sites visited will be in geographic proximity to one another, and that certain areas of the park (e.g. coastal, far northeast) are probably going to be underrepresented in the final site list, as it is more difficult to arrange shared helicopter time in those areas. Instead, the lowest numbered unsampled sites that can be accessed affordably based on logistical factors will be sampled. Although this modified sampling scheme will complicate analyses of the data, such challenges are an inevitable consequence of attempting to monitor a large, remote landscape with finite resources.

Sentinel sites have been selected based primarily upon ease of access to minimize the cost of repeated sampling (Table 5). In WRST, the sentinel sites are located along the Nabesna and McCarthy Roads. In DENA, the sentinel sites are located along the Park Road and were selected to coincide with sites that have been sampled for invertebrates since 1994 as part of the Denali Long Term Ecological Monitoring Program (LTEM, see Milner et al. 2003). Potential sentinel sites for YUCH are still being evaluated, but will be located along the Yukon River corridor where they can be accessed by motor boat, or adjacent to airstrips. Although the list of potential sentinel sites is of necessity limited, every effort has been made to make the final set as ecologically representative as possible.

Sampling Frequency and Rotation Schedule

Sentinel sites will be sampled annually during an index period from late June through late August. Additional sampling will be conducted at sentinel sites in the spring (early May through early June) and the fall (September) each year, as resources allow. This constitutes the core program, which we expect to be sustainable even with diminishing budgets. Although these sites do not fully capture the

ecological gradients in the network, they provide a reasonable cross-section of stream types and cover a large geographical area. The number of potentially accessible sites currently exceeds the number of sentinel sites, which would allow us to increase the number of sentinel sites in the core program if budgetary considerations force us to restrict the number of remote synoptic sites that are sampled.

Synoptic sites will be sampled with an approximately 10-year return interval, also during the index period of late June through late August, with the number of sites sampled per year varying from park to park, depending on the total number of synoptic sites in that park. Each year, therefore, the goal will be to sample 10% of the total number of synoptic sites in the network. For each park, 10 panels have been established, with a 10-year return interval for each panel. For WRST, there are a total of 60 synoptic sites, constituting 10 panels of six sites each. For DENA, there are a total of 30 synoptic sites, constituting 10 panels of three sites each, and for YUCH there are a total of 20 synoptic sites, constituting 10 panels of two sites each.

During the development of the program, these panels were rolled out on a staggered schedule. Synoptic sampling for WRST began in 2008, for DENA in 2010, and for YUCH in 2011. Therefore, the complete set of synoptic sites will in principle have been sampled once in 2017 for WRST, in 2019 for DENA, and in 2020 for YUCH, although the actual time may vary depending on year-to-year logistical challenges. Network wide, then, there will be a total of 110 synoptic sites, 11 of which will be sampled each year, and 14 sentinel sites, each of which will be sampled every year, for a total of approximately 25 sites sampled each year. In addition to these, a varying number of judgment sites will be sampled each year, and a varying subset of the sentinel sites will be sampled more than once per year, bringing the total number of sampling visits each year to approximately 30. Additional visits to sentinel sites for temperature sensor replacement and sonde measurements are not counted in this total. Through 2016, we have been able to roughly meet this schedule. In WRST, 47 synoptic sites have been sampled over eight years, for an average of just under six per year. For DENA, 22 synoptic sites have been sampled over six years, for a total of just under four per year (however, seven of these are coincidentally sentinel sites that have been sampled since 2007; when these are eliminated, we have sampled 15 GRTS sites in six years, or just under three per year). In YUCH we have sampled eight synoptic sites in five years, or between one and two sites per year.

This schedule will be continuously evaluated and adjusted as necessary according to the resources available. Because the vast majority of synoptic sites are only accessible by helicopter, it will not always be possible to meet the goal of maintaining a strict rotation schedule for each park. Inevitable deviations from the set rotation schedule will reduce our ability to detect regional trends moderately, but reflect the realities of implementing a large-scale, long-term monitoring program in a remote landscape on a limited budget.

Overview of Field and Laboratory Methods

Field Season Preparation, Field Schedule, and Equipment Setup

Prior to the field season, in April or May, all observers should review the entire protocol, including all of the SOPs. Special attention should be paid to SOP 1: Field Season Preparation, SOP 4: Training, and SOP 8: Field Methods. Proper calibration of all the equipment and familiarity with the procedures for data collection is essential for the generation of reliable data over the long term, so it is imperative that each observer successfully complete the training program. The training program will help reduce inter-observer errors and maximize data consistency throughout the duration of the monitoring program.

All of the equipment and supplies listed in SOP 5: Field Trip Mobilization and SOP 8: Field Methods should be organized and made ready for the field season well in advance of the first scheduled field trip, to allow plenty of time to order missing supplies or repair faulty equipment. To maintain maximum flexibility in scheduling and to account for potential damage or loss of equipment and/or supplies in the field, spare equipment and extra supplies of all consumables need to be available for each planned field trip.

To facilitate logistical planning and ensure completion of all park and agency compliance requirements, potential sampling locations should be selected well in advance of the field season. Generally, two to three streams should be scheduled for sampling each field day depending upon their proximity to one another. The number of streams that can be sampled in one day will depend on their proximity to access points (roads, landing lakes, rivers) and to one another. When sites that have not been previously assessed are to be included in a sampling schedule, it is important to account for the potential that some or all may be either inaccessible or unsafe to sample, by including nearby sites. Weather, fire, and the availability of appropriate transportation are substantial limitations to access in these remote parks. Hence, a reasonably flexible schedule is essential.

Continuous Temperature Monitoring

Continuously recording water temperature will allow us to detect changes in the annual temperature regime of streams and rivers across the network. Detailed procedures for the deployment of continuous temperature dataloggers are given in SOP 3: Continuous Monitoring of Temperature. A variety of small, self-contained dataloggers are available that can record thousands of independent temperature measurements. Currently the CAKN stream monitoring program relies on Hobotemp ProV2 dataloggers, which are relatively inexpensive, have a five-year battery life, and can store up to 18,000 observations. The loggers are set to record one observation every hour, which allows approximately three years of data to be recorded. Initially, we deployed loggers in the spring and removed them in the fall to guard against loss of the units during spring breakup. However, subsequent pilot studies demonstrated that loggers that were carefully sited and adequately anchored could remain in place over the winter. Accordingly, loggers are now left in place for up to three years. Currently, the majority of easily accessible sites in WRST and DENA have been instrumented. Temperature loggers have also been deployed at a single site in YUCH, and additional loggers will be deployed if possible. To ensure data quality, the CAKN follows the guidelines and standards for

the collection of stream temperature data developed for the Western Alaska Landscape Conservation Cooperative (Mauger et al. 2014, 2015). These include pre- and post-deployment testing of loggers as well as the deployment of duplicate loggers.

Field Trip Preparation (Mobilization)

Field trip mobilization procedures are given in SOP 5, Field Trip Mobilization. Field preparation entails assembling gear and making sure it is in good working order, assembling sampling supplies and consumables, creating sample labels, preparing sample materials, preparing field data forms, preparing the data recorder for data entry, setting up the database for upcoming data, preparing field transportation and camping support for field crews, and other tasks required for successful sampling trips. Lists of streams to be sampled must be generated and a sampling plan must be established, along with contingency plans for poor weather or other confounding factors that arise.

Daily Field Startup

Each night, the group will discuss the next day's plans and establish the route for visiting streams to be sampled. The stream sampling crew then travels to the first stream for the day and follows the sequence of streams established the night before.

Reach Establishment and Relocation

Prior to arrival at the stream to be sampled, the crew will determine whether a sampling reach has already been established for that stream. The sampling reach for each stream will be identified and established during the initial survey visit (see SOP 8: Field Methods), according to methods established by the EPA National Rivers and Streams Assessment (USEPA 2013a, 2013b). The location will be recorded using a GPS receiver (see SOP 6: Using the GPS). Generally, the GPS location will correspond to the bottom of the sampling reach; exceptions should be recorded and included in the location information for that stream. If the stream has already been sampled, the procedures detailed in SOP 8: Field Methods should be followed to locate the bottom of the sampling reach. If no sampling reach has been previously established, the procedures of SOP 8: Field Methods detailing reach establishment will be followed.

Photographs and Spherical Panoramas

Photographs should be taken to document the stream, following the procedures described in SOP 8: Field Methods and SOP 9: Spherical Panoramic Photography. Photographs should be taken during every sampling event to document conditions at the stream. At minimum, these should include upstream and downstream photos from the bottom of the sampling reach; however, it is very desirable to create a spherical panorama if conditions permit. The bottom of the reach is a good location for spherical panoramas. Additional photo points can be marked in the GPS to geotag specific photograph locations. It is helpful to have a compass bearing for the camera direction if a photograph is to be geotagged accurately.

Water Chemistry

Water chemistry sampling will occur as described in SOP 8: Field Methods. Field methods and quality assurance for water chemistry sampling and data collection are based on the EPA National Rivers and Streams Assessment protocol and quality assurance plan (USEPA 2013a, 2013b).

Samples should be collected at the bottom of the sampling reach, in the thalweg. There are two components to the water chemistry sampling. Instantaneous measurements of temperature, specific conductivity, dissolved oxygen, and pH are collected using a multiparameter sonde. In addition, water samples are collected, processed, and preserved for later laboratory analysis of solutes (Table 6). Water samples should be collected before any other sampling activity commences, to minimize entrainment of fine sediment or organic matter. Disposable nitrile gloves should be worn during all steps involved with water sample collection. After rinsing the collection bottle three times with stream water, samples should be collected from the thalweg by submerging the collection bottle to at least one third of the thalweg depth. Unfiltered samples should be transferred to acid-washed Nalgene high-density polyethylene (HDPE) bottles, kept cool and in the dark, and frozen as soon as possible. Filtered samples should be filtered on site using disposable 0.4 mm polycarbonate filters and then kept cool and dark. Samples should be frozen as soon as possible, except those that are to be analyzed for silica and dissolved organic carbon, which should be refrigerated.

Table 6. Water chemistry parameters collected by the CAKN stream monitoring program.

Collection Method	Parameter
Recorded in the field using multiparameter sonde	Temperature
	Specific conductivity
	Dissolved oxygen
	pH
Obtained from laboratory analysis	–
Nutrients	Total nitrogen
	Total phosphorus
	Total dissolved nitrogen
	Total dissolved phosphorous
	Nitrate+nitrite nitrogen
	Ammonia nitrogen
	Dissolved organic nitrogen (calculated)
	Phosphate phosphorous
	Dissolved organic carbon
Base Cations and Base Anions	Sodium (Na ⁺)
	Calcium (Ca ²⁺)
	Magnesium (Mg ²⁺)
	Potassium (K ⁺)
	Chloride (Cl [–])
	Sulfate sulfur (SO ₄ ^{2–})
Other	Total alkalinity
	Specific conductivity
	pH

Aquatic Macroinvertebrates

Field methods and quality assurance for the collection of macroinvertebrates are based on methods originally developed for the EPA Environmental Monitoring and Assessment Program (EMAP) and now used in the EPA National Rivers and Streams Assessment (USEPA 2013a, 2013b). SOP 8: Field Methods details the procedure for collecting macroinvertebrate samples. Macroinvertebrates are collected using a modified net that combines elements of Surber and D-net samplers, with a 500 μm mesh and a defined 0.09 m^2 sampling area. Sampling occurs at all 11 transects (see physical habitat characterization, below), with net placement varying between left, right and center of each transect in a systematic fashion. In situations where a stream is too large to be crossed safely, sampling is confined to the portion of the transect that is safely wadeable. At each sampling location, the entire area defined by the sampling frame is thoroughly searched for macroinvertebrates by individually rubbing cobbles in front of the net opening and subsequently disturbing the remaining substrate by raking to a depth of approximately 10 cm. All 11 samples are composited into a single reach-wide sample, macroinvertebrates and organic detritus are separated from cobble and gravel, and then immediately preserved in 70% ethanol.

Benthic Diatoms

Field methods and quality assurance for the collection of benthic diatoms are also based on methods originally developed for EMAP and now used in the National Rivers and Streams Assessment program (USEPA 2013a, 2013b). SOP 8: Field Methods details the procedures for collecting diatom samples. At each of the 11 transects where macroinvertebrates were collected, an appropriate cobble will be haphazardly selected along the same cross section used for macroinvertebrate sampling (1 m upstream of the transect itself). Cobble selection is shifted one “unit” to the right (i.e., if macroinvertebrates were collected in the center of a given transect, a cobble will be selected on the right). A defined area (12 cm^2) of each cobble is scrubbed and scraped to remove diatoms and the material collected is composited into a single reachwide sample. The total volume (diatoms plus rinse water) is recorded and a 40 mL subsample removed and preserved with 2 mL Lugol’s solution. At transects where only soft sediments are present, a 60-mL syringe will be used to collect a 60 mL mixture of water and sediment, which will be vigorously shaken in a 1-liter Nalgene bottle before decanting the liquid portion into the composited sample.

Physical Habitat Characterization

Physical data collection protocols and quality assurance are based on methods detailed in the EPA National Rivers and Streams Assessment protocol (USEPA 2013a, 2013b). Detailed procedures for physical habitat characterization are provided in SOP 8: Field Methods. At each of 11 transects spanning the reach, crews will measure depth (five measurements), width (wetted and bankfull), channel height (bankfull and incised), undercut banks, canopy cover (six measurements), and substrate size class (using a gravelometer—five measurements at each of the depth measurement locations). In intertransect segments, crews will measure thalweg depth and habitat type (ten measurements), width (one measurement), substrate (five particles along width measurement cross-section), woody debris (by number and size class), and fish cover—macrophytes, filamentous algae, boulders, and undercut banks (qualitative estimate of areal cover).

Discharge

Field procedures and quality assurance for the collection of discharge data are based on methods developed for the EPA National Rivers and Streams Assessment (USEPA 2013a, 2013b). Detailed instructions for collection of discharge data are provided in SOP 10: Discharge Measurement. In general, discharge measurements will be conducted at or near the bottom of the sampling reach after other data collection has been completed. Ideally, discharge data will be collected in a single-thread section of the stream with minimal turbulence, where flow is as close to laminar as possible. Examples include runs, glides, and pool tails. Typically 20 equally spaced velocity and depth measurements will be collected across a transect perpendicular to the flow using a digital flowmeter and top-setting wading rod. These measurements will be used to calculate discharge following the procedures in SOP 10: Discharge Measurement.

Site Notes

Site notes constitute an important observational component of the data collection effort at each site. To maximize the comparability and completeness of the site notes, a set of standard site note categories has been developed. Some of these (weather, channel constraint, channel type, dominant substrate class, forest health, river stage, evidence of recent high flow event, water color, and clarity) include menu-driven options as well as a descriptive component and can easily be recorded electronically in the Trimble field computer using the data dictionary, including brief explanatory notes. Others are descriptive only and are recorded on data sheets (basin description, riparian corridor description, evidence of human impact, animal encounters).

Decontamination

Before leaving the field site, the crew will ensure there are no contaminating pieces of debris on personnel or any sampling equipment or aircraft. Humans are the most effective vectors for the spread of vegetation and aquatic biota, due to our mobility. The CAKN program must be especially conscientious about not spreading noxious and invasive non-native species among the streams and rivers of the network parks. Therefore, a decontamination procedure will be followed prior to moving from one stream to the next and before returning to base camp. This procedure is detailed in SOP 11: Decontamination.

Field Trip Demobilization

Upon returning from the field, the crew must complete the tasks outlined in SOP 12: Field Trip Demobilization. Successful completion of these procedures will ensure that equipment and materials are in order and ready for the next field excursion, samples are treated appropriately, and that all data are transferred correctly and stored securely.

Laboratory Methods

Water, diatom, and macroinvertebrate samples to be processed by outside labs are logged into the database upon returning from the field. This allows for tracking of samples, creation of inventory lists, and a cross-check for QA/QC when lab results are received. Once data are received from laboratory sources, they are imported into the database following the procedures detailed in SOP 15: Data Management.

Water Chemistry

Water samples are submitted to a professional laboratory for chemical analysis. The laboratory must be qualified and experienced in the detection and quantification of low-level solutes, and in working with complex chemical matrices. The water chemistry of streams in the CAKN is complex, and nutrients generally occur at very low concentrations. Ideally, the same laboratory should be used every year in order to minimize variability in data caused by differences among laboratories in conditions, experience or methodology. Water samples are currently analyzed by CCAL (Cooperative Chemical Analytical Laboratory) at Oregon State University, which specializes in low-level detection of ambient stream water solutes. The methods used for these analyses are listed in Table 7. Quality assurance/quality control procedures for analysis of water samples are described in SOP 12: Water Chemistry Laboratory Procedures and are similar to those detailed for the EPA National Rivers and Streams Assessment (USEPA 2013b).

Table 7. List of methods for chemical analysis of water samples

Water Quality Variable	Method
Alkalinity	APHA 2320 with modification (CCAL)
Ammonia	APHA 4500-nh3 G; EPA 350.1
Calcium	APHA 3111 with modification (CCAL)
DOC	APHA 5310 B
Chloride	APHA 4110; EPA 9056A
Specific conductivity	APHA 2510
Magnesium	APHA 3111 B
Nitrate	APHA 4500-NO3
pH	APHA 4500 H
Orthophosphate	APHA 4500-P E; EPA 365.2
Total nitrogen	APHA 4500-NO3 F; APHA 4500-P J. Persulfate digest
Total phosphorus	APHA 4500-PB; APHA 4500-P E; EPA 365.2
Potassium	APHA 3111 B
Silica	APHA 4500-SiO2
Sodium	APHA 3111 B
Sulfate	APHA 4110 B

Diatoms

Due to budgetary constraints, diatom samples collected since 2013 are currently being archived for analysis during break years, when funding normally dedicated to field work can be redirected to laboratory analysis. Diatom samples will be submitted to a professional laboratory for taxonomic analysis, where they will be processed and identified to the lowest practical taxonomic level, generally species. A minimum of 800 valves will be identified, corresponding to 400 organisms. Ideally, the same laboratory should be used every year in order to minimize variability in data caused by differences among laboratories in conditions, experience, or methodology. Samples are currently analyzed by EcoAnalysts, Inc., which provides diatom taxonomy services for the EPA National

Rivers and Streams Assessment. Laboratory methods for processing and enumeration are described in SOP 13: Diatom Laboratory Procedures. Samples from the field will be logged in and stored until they can be shipped.

To ensure that the data collected by the CAKN monitoring program are compatible with data collected by other investigators and are as accurate as possible, a robust QA/QC program is required. Internal QA procedures for the laboratory are detailed in SOP 13: Diatom Laboratory Procedures and are identical or similar to those specified for the EPA National Rivers and Streams Assessment (USEPA 2013b). Quality control will be achieved by requiring the contract taxonomist to submit a randomly selected subset of at least four samples from the current year to an independent taxonomy laboratory. Currently the independent laboratory is the Phycology Section of the Patrick Center for Environmental Research at the Philadelphia Academy of Natural Sciences. Reconciliation to the 95% agreement level will constitute an indication of adequate data quality, although 100% agreement should be the goal. Digital images and original slide mounts will be maintained for possible future re-analysis; currently these are stored at the Fairbanks Administrative Center.

Aquatic Macroinvertebrates

Macroinvertebrate samples will be submitted to a professional laboratory for taxonomic analysis, where they will be sorted and identified to the lowest practical taxonomic level, generally genus. Chironomid midges will also be identified to genus. A minimum of 500 organisms will be identified from each sample. A 500-organism subsample is the standard effort level for the EPA National Rivers and Streams Assessment (USEPA 2013a, 2013b). Where fewer than 500 organisms are present, the sample will be completely enumerated. Ideally, the same laboratory should be used every year in order to minimize variability in data caused by differences among laboratories in conditions, experience, or methodology. Currently, macroinvertebrate samples are analyzed by Cole Ecological, Inc. Laboratory methods for sorting and enumeration are described in SOP 14: Macroinvertebrate Laboratory Procedures. Samples from the field will be logged in and stored until they can be shipped. Due to variability within and among samples in the taxonomic resolution that can be achieved, the CAKN has established a set of Operational Taxonomic Units (OTU) to assure that taxa are not double counted (Cuffney et al. 2007, Simmons, unpublished).

To ensure that the data collected by the CAKN monitoring program are compatible with data collected by other investigators and are as accurate as possible, a robust QA/QC program is required. Internal QA procedures for the laboratory are detailed in SOP 15: Macroinvertebrate Laboratory Procedures and are identical or similar to procedures detailed for the EPA National Rivers and Streams Assessment (USEPA 2013b). Quality control of taxonomic data is a critical issue in all invertebrate studies, and of particular importance in large-scale biological assessment programs (Stribling et al. 2003). Quality control will be achieved by requiring the contract taxonomist to periodically submit the entire macroinvertebrate reference collection, as well as a randomly selected subset of 10% of the samples from the current year, to an independent taxonomy laboratory. Currently the independent laboratory is EcoAnalysts, Inc., which provides invertebrate taxonomy services for the National Rivers and Streams Assessment. Reconciliation to the 95% agreement level will constitute an indication of adequate data quality, although 100% agreement should be the goal.

The maximum interval between QC events will be five years. Any retroactive adjustments to identifications from previous years will be documented and propagated through the database. All samples are maintained and stored for possible future re-analysis. Currently the samples are stored by the taxonomy laboratory; however, in the future these samples will be archived and stored at the University of Alaska Museum of the North.

Method Comparability

The field and laboratory methods described in the protocol have been designed to generate data that are maximally comparable with other major stream and river monitoring programs across the United States. Field methods were largely based upon existing methods published by the USEPA and used by most state and federal agencies as part of the National Rivers and Streams Assessment (USEPA 2013a), including those used in pilot studies conducted by the Alaska Department of Environmental Conservation as part of the EMAP Wadeable Streams Assessment (now NRSA, Rinella and Bogan 2008). The survey design for selecting synoptic monitoring sites for the CAKN program is also based on the survey design for the NRSA program, although we have been forced by logistical and budgetary considerations to modify it somewhat, as discussed in the Survey Design section of this narrative and in SOP 2: Sampling Design and Site Selection. Our methods are also comparable with those used in other bioassessment studies conducted by the Alaska Department of Environmental Conservation (Rinella and Bogan 2007; Jessup et al. 2005; Rinella et al. 2005). While our methods are qualitatively different in some respects from methods used by the USGS as part of the National Water Quality Assessment (NAWQA, Gilliom et al. 1995; Moulton et al. 2002), as well as for ongoing USGS data collection in Alaska (e.g., Brabets and Ourso 2006), the data generated are comparable. Similarly, our methods are similar to and comparable with methods used by the U.S. Forest Service as part of the large-scale PACFISH/INFISH Biological Opinion Effectiveness Monitoring Program (Heitke et al. 2011), as well as to methods used by the Western Center for Monitoring and Assessment of Freshwater Ecosystems (Hawkins et al. 2003). Finally, these methods are also comparable to pilot studies being conducted by the U.S. Fish and Wildlife Service in Alaska as part of that agency's inventory and monitoring program (Rinella and Bogan 2006, Rinella, pers. comm.) and to methods used in the recently implemented Bureau of Land Management monitoring program in interior Alaska (Scott Miller, BLM, pers. comm.). The laboratories that analyze the water samples, diatom samples, and invertebrate samples collected by the CAKN stream monitoring program are also used by state and federal agencies involved in water quality assessment.

Data Management

The project manager will be responsible for the safekeeping and organization of the data sheets and ensuring that data are entered into the database. Data management protocols are all detailed in SOP 15: Data Management.

Database Design

Most of the data associated with this project are housed in a single database. This database has a two-tiered architecture, in which the application's presentation (forms, queries, and reports) is in Microsoft Access, while the underlying data model and business logic are contained in a Microsoft SQL server database. The Access file is commonly referred to as the front end, while the SQL server database is commonly referred to as the back end. The SQL server is located at the Fairbanks Administrative Center office building, and the Access front end is kept on the CAKN network drive: J:\Monitoring\Streams\Database\. The database keeps information about each stream sampled in the table tblSites. This contains information about the streams that doesn't generally change through time, such as the location and basic characteristics. Standard data collected at each stream during a sampling visit are then recorded in the table tblEvents, which is related to tblSites based on the Site Code assigned to each entry in tblSites. Each entry in tblEvents must have a Site Code field entry that matches one of the Site Codes listed in tblSites. The table tblEvents contains the observational data collected regarding the characteristics of the stream at the time of the visit, and allows for entry of comments about the current condition of the stream. When data are entered into the database, the main entry form that is used is frmMain, which displays the fields from tblEvents. In addition, the form contains tabbed forms for entering specific data into separate tables. The tabs include forms for Water Chemistry, Invertebrates, Diatoms, Sonde Data, Discharge, and Physical Habitat. When entering a particular data type, one can navigate to the appropriate form.

All of the data entered into forms using the frmMain are automatically tagged with the same Site Code and Sample Date as the data being entered into tblEvents. This results in all of the ancillary data collected at a given site on a given date being linked together through the table tblEvents. Any data entered into any one of the ancillary data tables must have a matching entry in tblEvents. The combination of Site Code and Sample Date provides a simple and robust primary key, allowing any suite of variables to be linked together in a view or query.

Data Entry and Storage

While in the field, data will be entered using a variety of techniques:

1. Direct entry into the database using a tablet PC
2. Assigning attributes to spatial locations using Trimble GPS units
3. Logging sample information using YSI MDS 650 field computers
4. Filling in paper data sheets (printed on all-weather paper)
5. Ancillary data and observations recorded in field notebooks

At the end of each day, electronic data will be backed up to a second source, as outlined in SOP 15: Data Management. All electronic data should be copied to a second source, such as a field laptop or thumb drive. Paper forms should be filed in a safe location. Data from field forms may also be entered into the database using the tablet PC at the end of the field day, if time allows; these sheets should be clearly marked as having been entered into the database.

At the end of a field excursion, all data will be transferred to the CAKN network drive and filed in the folder structure according to the conventions outlined in SOP 15: Data Management. Once data have been safely stored on the network drive, any duplicate copies on the field laptop or thumb drives will be deleted, in order to reduce potential for confusion about which file is the most recent. If time allows, data from datasheets may be entered into the database using the tablet PC.

At the end of the season, the data manager for the project, currently the network aquatic ecologist, must ensure that all field data collected throughout the summer have been entered, checked, and imported into the database. All instances of the database on tablet PC computers must be concatenated to the main database on the Fairbanks Administrative Center SQL server. These procedures are outlined in SOP 15: Data Management, and a Data Processing Checklist is used to track all the actions taken for all data. Because there are so many different instruments and tools used to collect data, often each requiring specific protocols for downloading, processing, and importing or archiving data, it is essential to keep track of all data processing and management steps as they are completed. A Data Processing Checklist will be completed for each park where data are collected in any given year.

Laboratory data received following sample analysis must be imported into the appropriate tables in the database. Protocols and sample scripts required for accomplishing this import are described in SOP 15: Data Management. The original documents containing the lab results will be filed in the appropriate folder in the Laboratory data folder for this project.

Data Verification

Data verification is an essential part of data collection. It is critical that the collected data are carefully reviewed prior to leaving a stream. Once all data have been collected, the observer who has been recording data asks a second observer to review the data sheets and Trimble data dictionary for completeness. It is this person's responsibility to inspect the data sheets and fill in any missing data. This is the most important point of data verification as it is the last opportunity to acquire any missing data for that site visit. Data collection will be verified again at the end of the day after all data have been collected. After the data have been entered into the Access database, the project manager will verify the data are accurately entered into the database by randomly comparing the data sheets to the database.

Archiving Data

Once data have been cleaned and properly stored, a copy of the SQL server database (including both the .mdf and .ldf files) will be archived on the CAKN network drive. This can be accomplished using the same SQL Back-Up Tool program used for creating field backups of the database on the tablet PC. This is an additional security measure to the back-ups regularly performed on the SQL server

database by information technology (IT) personnel at the Fairbanks Administrative Center. These regular backups are invaluable, for if damage to the database should occur, IT personnel are able to retrieve a copy of the database from any given date. When changes are made to the Access front-end for the database, the previous version of the front-end will be moved into a folder designated with the year within the Database folder. Only the current version of the front-end will be kept in the root Database folder. When data are complete, they may be exported to STORET, an operational system maintained by the EPA where many governmental agencies and private entities actively post water quality data. Data entered into STORET must be accompanied by information on where the sample was collected (latitude, longitude, state, county, hydrologic unit code, and a brief site identification), when the sample was collected, the medium sampled (e.g., water, sediment, fish tissue), and the name of the organization that sponsored the monitoring. In addition, STORET requires information on why the data were gathered, sampling and analytical methods used, the laboratory used to analyze the samples, the quality control checks used when sampling and handling the samples, quality control methods during data analysis, and the personnel responsible for the data. The National Park Service is developing a tool to allow extraction of water quality data from Access databases such as the Stream Monitoring database, so that the data may be easily uploaded into STORET. Specific procedures for accomplishing this are in development and will be incorporated into the Data Management Plan as they are available.

Metadata

Metadata describe the attributes of an information bearing object (IBO). IBOs for this project can be in many formats, including documents, data sets, databases, fields within databases, GIS files, images, and biological collections. It is essential to include accurate metadata with any IBO, because it provides critical information regarding the format of data to people who are interested in interpreting the data. A metadata record for this project includes representations of the content, context, structure, quality, provenance, condition, and other characteristics of an IBO. Metadata for this project come in many different forms. They are embedded within the SQL server database, where each table and each field have a description. Database forms in Access display field descriptions at the bottom of the page when a field is activated. Access queries or views are all tagged with a description of what the query accomplishes, whether it is integral to the functioning of the database, and when it can be deleted if it is a temporary view. Another important venue for metadata is in GIS files. Many files may be produced during a GIS analysis process, some of which are more important than others. It is very easy to accumulate large numbers of similar files, and it becomes difficult to determine which files are most appropriate for use if metadata have not been included with the file. The National Park Service has a number of metadata templates available for use, and the NPS Editor tool for metadata is also an excellent resource for quickly assigning critical metadata to any files produced for this project. All GIS files will have, at minimum, a short description of the purpose, function, and provenance of the file. GIS files to be shared with the public or with other projects will require a more rigorous standard of metadata.

When creating documents for this project, it can be helpful to add metadata either directly in the document (adding a Notes worksheet in an Excel file, filling in the Document Properties fields in Word documents), or by including a separate Read-Me file in a folder with the associated documents.

Analysis and Reporting

Overview

Refer to SOP 17: Data Analysis and Reporting for more specific information on the analyses that will be performed with the data collected for this project, along with the reporting methods that will be used to present the data. The summaries provided below provide a detailed introduction to the approaches we will apply. Most analyses will be conducted using the appropriate packages in Program R (R Core Team 2016), a free statistical software environment. Multivariate analyses such as classification and ordination will generally be conducted using the program PCOrd (McCune and Grace 2002; Peck 2010).

Annual reports will be prepared each year. Annual reports will describe the results of each year's field activities and data collection in detail and include basic statistical summaries and data visualization as described below. Where appropriate, annual reports will also include basic analyses of spatial pattern and trend as described below (e.g., Simmons 2015). Annual reports will be published as part of the NRDS or NRTR report series. Annual reports will be made available on the CAKN website (<http://science.nature.nps.gov/im/units/cakn/reportpubs.cfm>) as well as being uploaded to the Integration of Resource Management Applications (IRMA) database (<https://irma.nps.gov/DataStore/Reference/Profile/2215908>).

Synthesis reports will be prepared every five to seven years, starting in 2018. The final sampling design for the program was implemented beginning in 2011, so the first synthesis report will be published seven years after that. Synthesis reports will focus on detection of trends at both sentinel sites and at the network scale, as described below. Synthesis reports will be published as part of the NRDS or NRTR series.

Periodically, more extensive or targeted analyses will be conducted with the assistance of the network biometrician. The results of these analyses will be published either as part of the NRTR series or in peer-reviewed journal articles or both, as appropriate. Other methods of reporting will include formal presentations at scientific conferences (e.g., Simmons and Ostermiller 2012), as well as informal presentations to park and network staff and the general public.

Research Briefs will be published or updated when warranted. Currently, the CAKN stream monitoring program has four Research Briefs in circulation, covering hydrological monitoring, water quality, biological assessment of stream ecosystem condition, and climate change effects on stream ecosystems (Simmons 2012a, 2012b, 2011, 2010).

Reporting Exceedances of State of Alaska Water Quality Standards

Water chemistry data will be assessed each year to determine whether any collected values exceed the surface water quality standards defined by the Alaska Department of Environmental Conservation (ADEC). The most recent version of these standards was published in 2016 (ADEC 2016). Any exceedances will be reported to the Division of Water at ADEC. For reporting purposes, all waters in the network will be assessed under Designated Use Class C ("growth and propagation of fish, shellfish, other aquatic life, and wildlife"), as defined in 18 AAC 70.020. Water quality

standards that are applicable to the data collected by the CAKN stream monitoring program are listed in Table 8. Note that exceedances for most pollutants under these standards require either continuous data collection, or at least multiple data points, over a period of hours to days and are therefore not compatible with data collection methods employed by the CAKN, which are typically restricted to one, or at most several, data collection events per year.

Table 8. State of Alaska surface water quality standards for selected attributes under Designated Use Class C. Only standards that apply to instantaneous values are listed. For many pollutants, standards are defined only for acute (e.g., 1-hour average) or chronic (e.g., 30-day average) concentrations, which are not measured by the CAKN monitoring program.

Attribute	Standard for waters used by anadromous and resident fish	Standard for waters not used by anadromous and resident fish	Notes
Dissolved Oxygen	> 7 mg/L	≥ 5 mg/L	May not exceed 17 mg/L
pH	Not < 6.5 or > 8.5	Same	May not vary more than 0.5 pH unit from natural conditions
Temperature	≤ 20°C; for migration routes and rearing areas ≤ 15°C; for spawning areas ≤ 13°C	≤ 20°C	Weekly average temp may not exceed site-specific requirements need to preserve normal species diversity or to prevent the appearance of nuisance organisms.
Alkalinity	≥ 20 mg/L as CaCO ₃	Same	Except where natural alkalinity is lower

Routine Data Summaries

Summary statistics for water chemistry, temperature, and biological data will be generated annually to provide basic information related to differences between sampling locations, parks, and any other groupings such as network stream classification scheme. In general, nonparametric statistical methods will be used to characterize the data collected by the CAKN program. Environmental data are characterized by three attributes that typically result in a non-normal distribution. These are: a lower bound of zero, the presence of outliers on the positive side, and a resulting positive skewness. Accordingly, environmental data often violate a key assumption of parametric statistical methods. Median values rather than mean values will be used to summarize the central tendency of the data. In examining geographic and temporal patterns in water chemistry, temperature, and biological parameters like species richness and diversity, median values are more useful than mean values in that they represent typical values and are resistant to the influence of outliers and skewed distributions (Helsel and Hirsch 2002). Maxima and minima will also be calculated and reported, as they can be more important ecologically than mean or median values.

Extreme values, or outliers, are common in environmental data such as water chemistry. Although such extreme values can be informative and important, they can also have a large influence on parametric summary statistics (Helsel and Hirsch 2002). Outliers can be a result of a measurement or recording error; however, they can also represent rare events or observations from other populations. Outliers in monitoring data will be identified using graphical methods (box plots, normal probability

plots) and examined to determine whether they can be attributed to measurement or recording error. If so, they will be excluded from further analyses. If they cannot be attributed to measurement or recording error, they will be retained for subsequent analyses. Because nonparametric analysis methods will be used, outliers will not have an undue effect on the results.

High variability is another important characteristic of environmental data. Because parametric summary statistics of variability or spread (sample variance, standard deviation) are strongly influenced by outliers, we will use the interquartile range (IQR) to summarize variability. The IQR (defined as the 75th percentile to the 25th percentile) measures the range of the central 50% of the data and is not influenced at all by outliers (Helsel and Hirsch 2002).

For water chemistry parameters characterized by a substantial percentage of “nondetects” (typically values that are below the laboratory detection limit for that parameter) methods designed to handle these so-called censored data will be used to generate summary statistics. For streams in the CAKN, total dissolved phosphorous, phosphate-phosphorous, nitrate-nitrogen, and ammonia nitrogen are the primary types of censored data that are collected. These methods are based on the use of percentiles or ranks for calculation of statistical summaries and for hypothesis testing (Helsel and Hirsch 2002).

Graphical methods will also be used to generate annual data summaries and for exploratory data analysis to inform further study. For individual parameters, four types of graphical methods will be used. These are boxplots, quantile-quantile (Q-Q) plots, scatterplots, and cumulative distribution function (cdf) plots. All four methods provide important visual information regarding the distribution of the data, either among sampling locations or across time at a single sampling location. For example, Q-Q plots can be used to determine whether differences between groups of data are additive or multiplicative.

Multivariate datasets, which include primarily macroinvertebrate and diatom community data (although water chemistry data can also be considered to be multivariate), will be visualized using ordination techniques. Primary among these will be Nonmetric Multidimensional Scaling (NMDS), which has advantages over other multivariate ordination techniques in that it makes no assumptions about the properties of the underlying species distributions and so is able to accurately identify gradients beneath nonnormal distributions, which typically characterize ecological data (Wentworth and Ulrey 2000). Principal Components Analysis (PCA) will be used in cases where an assumption of multivariate normality seems reasonable. Prior to any analysis, invertebrate and diatom taxa lists will be adjusted to ensure each reported taxon is unique by converting ambiguous taxa designations to Operational Taxonomic Units (OTU, Cuffney et al. 2007).

The results of these exploratory analyses will be used to direct more in-depth study. In particular, the network is still in the process of developing a robust stream classification scheme. Classification is a critical step in improving our understanding of spatial and temporal patterns across the network as well as in improving our power to detect change. Different stream types/classes are likely to respond differently to global drivers. Accounting for variability across sites via classification will therefore increase our ability to detect changes in ecosystem attributes. A variety of classification methods, including cluster analysis (k-means, UPGMA, Classification and Regression Trees [CART], and

random forests) and ordination (NMDS, PCA) will be used to search for stream groupings based on landscape, chemical, and/or biological attributes. The robustness of the groupings obtained by each method will be tested using various measures of classification validity, including bootstrapping, silhouette analysis, the Dunn index, and classification strength (Van Sickle 1997).

Biological Assessment

Overview of RIVPACS Modeling

Biological assessment of ecological condition across network streams will be accomplished through the application of empirical predictive models, commonly referred to as RIVPACS, or O/E models (e.g., Clarke et al. 1996; Hawkins 2006). These models use natural environmental gradients to predict the species composition of invertebrate, diatom, or fish communities that would be expected to occur at a given sampling site in the absence of impairment. The ratio of the number of expected fauna that were actually observed to the number of expected fauna, or O/E, represents a measure of the degree to which the biological community at that site remains intact. Significant deviations from expected conditions constitute a measure of biological impairment, or in more general terms, of ecological change away from expected conditions. Given appropriately defined thresholds for change detection, O/E scores can be used to evaluate ecological condition and hence water quality either at individual sites of interest or at regional or larger spatial scales. More generally, O/E scores can be used to detect any kind of change in ecological condition, including changes due to global drivers like climate warming.

The development of robust RIVPACS models is an iterative process, so only an overview of model construction is provided here, along with a brief description of the current RIVPACS model, based on invertebrate data collected from 2006–2011. We are currently in the process of updating the current CAKN model to include data collected through 2015, as well as data collected by other entities, including the U.S. Geological Survey and ADEC. Because RIVPACS models are designed to predict the expected community composition that would be observed in the absence of impairment, the models are built using data only from sites that are thought to be relatively free of human influence (Bailey et al. 2004). Although selection of these least-disturbed, or reference, sites can be challenging in many areas (Herlihy et al. 2008), it is relatively straightforward in a largely intact landscape like the CAKN. Log-transformed or presence-absence OTU-adjusted invertebrate and/or diatom data will be used to classify reference sites according to biological similarity in a cluster analysis. Discriminant function modeling, either best subsets linear discriminant modeling (Van Sickle et al. 2006) or random forests (Cutler et al. 2007), will then be used to identify sets of predictor variables that best discriminate among the biological groupings. All RIVPACS models the network has constructed to date have relied on random forest discriminant models. Although some predictor variables for RIVPACS modeling will be derived from field habitat and water chemistry data, the emphasis will be on extracting descriptive basin-level statistics for each site using GIS data. GIS-derived predictors have the distinct advantage that they are not subject to variation due to observer bias or field data collection methodology. Thus, the use of GIS-derived variables greatly increases the comparability of data collected at different times, by different observers, or by different monitoring programs.

Basins for each sampling reach will be defined as the upstream contributing area of each sampling location based on the geographic coordinates of the bottom of the reach. Basin delineation can be conducted using a number of tools that operate in ArcGIS, including TauDEM (<http://hydrology.usu.edu/taudem/taudem5/>) and Arc Hydro (Maidment 2002). Currently, basin delineation for the CAKN monitoring program is conducted by GIS specialists at ABR, Inc., using customized ArcGIS scripts that allow delineations for multiple basins to be accomplished in batch mode. Corrected shapefiles corresponding to each delineated basin are then used in ArcGIS to extract a large number of descriptive statistics for each basin (Table 9). Climate statistics are derived from the spatially explicit PRISM climate data models that are based on long-term averages (Daly et al. 2008). Other statistics are derived using DEMs, land cover, and other data layers as needed.

To test the condition of new sites of interest (generally referred to as “test” sites), the discriminant model is used to calculate the posterior probability of membership in each biological class for each test site. The posterior probabilities, in combination with the frequencies of occurrence of each taxon across the biological classes, are then used to calculate the probability that each taxon will be captured at each of the test sites. The sum of these probabilities for a given site across all taxa gives the expected number of native taxa that should be captured at that site (E). The ratio of the number of those expected taxa that are actually observed at the site (O) to E gives a measure of the degree to which the native fauna are intact. This ratio, O/E, is both site-specific and standardized, so it allows comparisons to be made among sites that have widely different native faunas.

Table 9. Examples of basin-level descriptive statistics derived for use in the development of RIVPACS models.

Category	Statistic
Climate	Mean precipitation and temperature (annual)
	Mean precipitation and temperature (by month)
	Mean maximum precipitation and temperature (annual)
	Mean maximum precipitation and temperature (by month)
	Mean minimum precipitation and temperature (annual)
	Mean minimum precipitation and temperature (by month)
Topography	Mean, minimum and maximum elevation
	Basin area
	Basin relief
	Basin aspect
	Channel gradient
	Longest distance to source
Other basin descriptors	Percent glaciation
	Percent lakes
	Drainage density
	Land cover type, percent by category
	Percent permafrost, percent by type
	Lithology, percent by category

To determine whether an observed value of O/E actually indicates a significant deviation from the expected or reference condition, the model must be assessed for precision and bias. By definition, the O/E score for a reference site should be 1.0; that is, we should always observe what we expect at reference sites. However, due to model error, the O/E scores of reference sites instead form a distribution centered on 1.0, if the model is unbiased. Deviations away from a mean score of 1.0 indicate a degree of bias in model predictions. Bias can also be assessed visually by evaluating a plot of O versus E. The spread of the distribution of reference site O/E scores, generally quantified by the standard deviation, gives an estimate of model precision and allows us to set statistically valid thresholds for change detection. Given a sufficient number of reference sites, the model is constructed using one set of sites and evaluated for precision using a second set of sites. For many programs, however, precision must be evaluated using the same set of reference sites that were used in model construction. This is the case for the CAKN stream monitoring program as well, until such time as sufficient reference data can be assembled.

CAKN RIVPACS Model

The CAKN has successfully developed two RIVPACS models in recent years (2011, 2013) and is in the process of developing a third model. Here I describe the construction and performance of the current iteration of the model, completed in 2013. Invertebrate and environmental data from 68 reference streams in DENA and WRST were used to develop the current RIVPACS model. The data were collected from 2006 to 2011. For sites that had been sampled in more than one year, a single site visit was randomly selected. Invertebrate abundances were converted to presence-absence prior to model construction. Six biological classes were identified using the unweighted pair-group method with arithmetic mean (UPGMA) clustering algorithm in PC-ORD, with between-sample similarity defined using the Sørensen index (McCune and Grace 2002). A random forest discriminant model to predict new sites into these biological classes was constructed using the randomforest library in R. Five thousand trees were constructed, with five variables used at each split (see Cutler et al. 2007). The resulting model used 31 environmental predictors; Table 10 lists the 10 most important of these variables. The final discriminant model had an out-of-bag estimate of error rate of 33.8%, with most misclassifications being into closely related groups. This discriminant model was combined with the frequency of occurrence of each taxon across all biological groups to create the final RIVPACS model.

Table 10. Ten most influential environmental predictive variables used in the CAKN RIVPACS random forest discriminant model. The Global Importance Value for a variable represents the mean decrease in the group prediction accuracy for the random forest discriminant model when that variable is omitted, averaged over all group predictions. All climate variables are derived from PRISM and represent mean values for the basin from 1971-2000. The complete discriminant model uses 31 predictors.

Variable	Interpretation	Category	Global Importance Value
Area.km	Watershed area	Stream size	5.79
Perimeter	Watershed perimeter length	Stream size	5.37
AnnMxTemp	Mean annual maximum air temp	Climate	5.3
JulMxTemp	Mean July maximum air temp	Climate	5.22
AnnMinTp	Mean annual minimum air temp	Climate	5.08
CVSlope	Variability of basin slope	Topography	4.85
MinElev	Elevation at sampling location	Topography/climate	4.82
EvergreenForest	% Evergreen forest in basin	Land cover	4.79
Pctlakes	% Basin area as lakes	Land cover/hydrology	4.57
Pctwetlands	% Basin area as wetlands	Land cover/hydrology	4.54

To test the model for precision and bias, invertebrate and environmental data from the same 68 reference sites used to construct the model were used, as discussed above. The mean O/E score of the reference sites for this model is 1.07, which indicates a slight negative bias in predictions.

Examination of a plot of O versus E (not shown) revealed that this negative bias is driven by modest underpredictions at sites with high E. In other words, at more diverse sites, the model predicts slightly fewer species than are actually observed. This is probably a reflection of the relatively small number of reference sites used in model construction, particularly given the large scale and ecological heterogeneity of the CAKN (J. Ostermiller, pers. comm.). Future iterations of the model that will include data from nearly 150 samples should alleviate this bias. There is a strong relationship between O and E ($r^2 = 0.86$), suggesting that variation in O is well predicted by E.

The precision of the model is reasonable, as reflected in the standard deviation of reference site O/E scores of 0.168. This is comparable to the precision of other large-scale RIVPACS models (Van Sickle et al. 2005; Hawkins 2006; Hargett 2012). Thresholds for the detection of change in ecological condition, or designation of a particular site as being in nonreference condition, for RIVPACS models are generally defined as the 10th and 90th percentiles of the reference site O/E distribution. These thresholds provide a balance between the risk of Type I and Type II errors appropriate to the implementation of an ecological monitoring program (Clarke et al. 1996; Ostermiller and Hawkins 2004). Using this definition, the thresholds for detecting change for the current CAKN RIVPACS model are an O/E score less than 0.84, representing a 16% loss of expected native taxa, or greater than 1.3, representing a 30% increase. In other words, over 10 years, this model is capable of detecting a net annual loss of less than 2% of native species diversity or a net annual gain of 3%. Future iterations of the model that include more reference site data are expected to exhibit greater precision and therefore greater sensitivity to detect change.

One powerful advantage of this idea is that in principle, change can be detected at sites that are being sampled for the first time, because RIVPACS generates a site-specific expected community composition and then merely quantifies any difference from those expected conditions. A site not in its expected condition can be inferred to have changed from that condition at some time in the past. Absent other proximal sources of anthropogenic or natural stress, alterations in condition are likely due to the effects of climate change.

Trend Detection

Water Chemistry and Temperature at Sentinel Sites

We will primarily use nonparametric methods to test for trend in measures of water chemistry and temperature at sentinel sites. Nonparametric methods are generally more appropriate for environmental data than parametric methods, due to the tendency of such data to be non-normally distributed (Helsel and Hirsch 2002). Accordingly, we will rely primarily on several robust nonparametric tests for trend, all of which are available as documented packages in R. In cases where seasonality is not thought to be a factor (for example, water chemistry parameters calculated only from samples obtained during the summer index period (late June through late August), we will use Theil-Sen nonparametric regression (Helsel and Hirsch 2002) to test for trend over time using the *sen* package in R. To test for the effects of environmental covariates that may obscure trends in response variables of interest, we will use the *nptrend* package in R to first model the response variable against each covariate using a LOWESS smooth, followed by testing the LOWESS residuals for trend using Kendall's tau (Helsel and Hirsch 2002).

In some cases it may be desirable to use a step trend test to compare two time periods rather than testing for a continuous trend. For example, historical water chemistry data are available for a number of streams in the network (e.g. Edwards and Tranel 1998). Comparing values measured in past decades with those currently being collected by the stream monitoring program is best approached using a step trend test. Accordingly, for these types of analyses, we will use a two-sample Wilcoxon test to test for differences between time periods.

In cases where seasonality is likely to confound detection of trends (e.g., for continuous water temperature data), the Seasonal Kendall test will be used to test for trend using the *seaken* package in R. Whereas in Theil-Sen regression, the computed slope is the median of pairwise slopes, in the Seasonal Kendall test, the slope is the median of all within-season pairwise slopes. As above, in cases where environmental covariates may also confound detection of trend, the *npseattrend* package in R will be used to first model the response variable against each covariate using a LOWESS smooth, and then the residuals will be tested for trend using the Seasonal Kendall test.

Power Analysis for Trend Detection of Water Chemistry Parameters at Sentinel Sites

To estimate the years of data that would be required to detect statistically significant changes in the values of water chemistry parameters (or of water temperature summary statistics) given the observed levels of interannual variability in data collected at sentinel sites since 2006, a power analysis was performed using the *powertrend* function in R. Because *powertrend* is a parametric power analysis package based on linear regression, it provides a very conservative estimate of power for the nonparametric tests the CAKN will rely on for trend detection. Nonparametric tests have

substantially more power to detect differences or trend than parametric tests when data are non-normally distributed, as is generally the case for environmental data, and tend to have equivalent power for normally distributed data (Helsel and Hirsch 2002).

To assess how variability in measured values for various water chemistry and temperature parameters will affect the ability to detect change, I first conducted a power analysis using *powertrend* at five potential levels of variability, as represented by the coefficient of variation (CV, defined as the standard deviation divided by the mean). Here the CV ranged from 0.05, corresponding to a low level of variation between values measured at different sampling times, to 0.25, representing a moderate level of variation. Power to detect change was evaluated for two values of α . Because the emphasis in a long-term monitoring program should be on detecting change where it is actually occurring, or in other words on minimizing the chance of Type II errors, it is appropriate to set α above the traditional value of 0.05 (Rawhouser et al. 2012). Accordingly, power was evaluated for $\alpha = 0.10$ and $\alpha = 0.20$. Following Rawhouser et al. (2012), the rate of annual change to be detected was defined to be 3%, and the sampling frequency was set at once per year. The results are shown in Tables 11a and 11b. For $\alpha = 0.10$, anywhere from 6 to 19 years of data would be required to detect an annual change of 3%, depending on the underlying variability of the parameter of interest. For $\alpha = 0.20$, the range is 6 to 17 years. In either case, the range of years of data required is well within the scope of the CAKN stream monitoring program, which has already collected as many as 10 years of data at some sentinel sites. Note that because *powertrend* assumes that errors scale with the magnitude of the parameter value, more data are required to detect increases than to detect decreases.

Table 11a. Years of data required to achieve a given statistical power to detect a 3% annual change in the value of a parameter as a function of interannual variation (represented by the coefficient of variation [CV]). Power values above 80% are in **bold**. Once power reaches 80% for both an increase and a decrease, no further calculations are shown for a given CV. $\alpha = 0.10$.

CV	Years of data	Cumulative % change	Power to detect increase	Power to detect decrease
0.05	6	18	76	81
	7	21	90	91
0.10	9	27	71	80
	10	30	82	91
0.15	12	36	72	84
	13	39	80	91
0.20	14	42	67	82
	16	48	81	93
0.25	16	48	64	82
	19	57	82	97

Table 11b. Years of data required to achieve a given statistical power to detect a 3% annual change in the value of a parameter as a function of interannual variation (represented by the coefficient of variation [CV]). Power values above 80% are in **bold**. Once power reaches 80% for both an increase and a decrease, no further calculations are shown for a given CV. $\alpha = 0.20$.

CV	Years of data	Cumulative % change	Power to detect increase	Power to detect decrease
0.05	6	18	89	100
0.10	8	24	74	81
	9	27	85	90
0.15	11	33	77	86
	12	36	84	93
0.20	13	39	75	85
	14	42	80	90
0.25	15	45	73	86
	17	51	81	94

To evaluate the actual variability of the parameters measured by the CAKN stream monitoring program, and hence the number of years of data that would be required to detect a 3% annual change in the value of those parameters, I looked at a representative set of water chemistry parameters from 12 sentinel streams where at least five years of data were available. Variability was again assessed using the coefficient of variation (CV). For sites that had been sampled in more than one season, only data from the index sampling period (late June to late August) were included in the analysis. Eight parameters were evaluated: pH, silicon concentration, total alkalinity, specific conductivity, sulfate-sulfur concentration, dissolved organic carbon concentration, total nitrogen concentration, and nitrate-nitrogen concentration. The results are shown in Table 12. Because the observed CV varied

substantially among individual streams, the median CV value was used to estimate the years of data that would be required to detect a 3% annual change, again with α set at either 0.10 or 0.20. For some parameters (pH, silicon), relatively few years are required, and the program already has sufficient data from some streams to detect change, whereas for others (DOC, total nitrogen, nitrate-nitrogen), more than a decade of data will be required. However, in general, it is clear that we will have the ability to detect this level of change within the next few years in most cases. Some individual streams exhibit a substantial variability, especially for nitrate-nitrogen, and change detection in these cases may require several decades of data.

Table 12. Median years required to detect a 3% annual change for representative water chemistry parameters, based on results from 12 CAKN streams with at least 5 years of data.

Parameter	CV range	Median CV	Median years to detect 3% annual increase $\alpha=0.1$	Median years to detect 3% annual increase $\alpha=0.2$	Median years to detect 3% annual decrease $\alpha=0.1$	Median years to detect 3% annual decrease $\alpha=0.2$
pH	0.008–0.031	0.015	4	3	4	3
Silicon	0.021–0.142	0.049	7	6	6	6
Alkalinity	0.054–0.183	0.092	10	9	9	8
Specific conductivity	0.046–0.178	0.093	10	9	9	8
SO ₄	0.08–0.241	0.149	13	12	12	11
DOC	0.10–0.473	0.199	16	14	14	13
Total nitrogen	0.057–0.435	0.203	16	14	14	13
Nitrate-nitrogen	0.069–0.734	0.251	19	17	16	15

Trend Detection for Water Chemistry at the Park or Network Scale

Generalized linear mixed models (Zuur et al. 2009) will be used to estimate status and long-term trends in water chemistry in streams across the network. These will be fit in a Bayesian framework using a model-based approach that can accommodate unbalanced sampling (e.g., different coverage extents in different years) and rotating panel designs (Gelman et al. 2004). Departures from the formal GRTS draw required due to access restrictions, or from the rotation schedule, can also be accommodated under this approach. Additional sites that were selected based on ease of access can be included, allowing the collection and use of much more data than would be possible under a strict design-based approach. Individual stream reaches will be treated as sampling units and trends at the reach and park levels will be estimated. Random effects at the level of the sampling unit will be used to explicitly address unbalanced sample sizes and revisit intervals for individual sample units. Spatially explicit models (Cressie and Wikle 2011; Diggle and Ribeiro 2010) may be used to help to account for variation across the landscape and will help assess status and identify trends that may otherwise be obscured. Covariates such as ecoregion, ecological subsection, lithology, elevation, landscape position, and basin area will also be included to help explain variation and reveal differences in status and trends across spatial scales (e.g., watershed vs. park unit). When applicable,

data from multiple parks will be used to increase precision and help identify change at the network level.

Trend Detection for Macroinvertebrate and Diatom Communities at Sentinel Sites

The CAKN will use a variety of methods to assess multivariate invertebrate and diatom community data collected annually at sentinel sites for change or trend in species composition. As discussed in the previous section, we will use the CAKN RIVPACS model to evaluate whether invertebrate samples collected at sentinel sites in years after the baseline period (2004–2011) have changed significantly from the expected composition, using the 10th and 90th percentiles of the reference site O/E score distribution as change detection thresholds.

Multivariate control charts are another approach that the CAKN will use for detecting change in invertebrate and diatom communities. Briefly, this approach examines whether the dissimilarity between the observed composition at time t and the multivariate centroid of previous observations (either a fixed baseline centroid or a moving centroid including all observations up to time $t-1$) is statistically significant (Morrison 2008; Anderson and Thompson 2004). Multivariate control charts can be applied at any spatial scale, from an individual site to the entire network. Although this method is relatively new to ecologists and has not yet been widely applied for ecological analyses, preliminary work shows that it is a robust approach for the analysis of change in lotic macroinvertebrate communities (A. Woodward, USGS, unpublished data).

Visualization of community data using nonmetric multidimensional scaling (NMDS) will also be used to assess changes in community composition. As discussed above, NMDS has advantages over other multivariate ordination techniques in that it makes no assumptions about the properties of the underlying species distributions and so is able to accurately identify gradients beneath non-normal distributions (Wentworth and Ulrey 2000). In addition, NMDS is able to handle data containing outliers, which can be important in identifying range shifts, but can cause problems for methods that assume multivariate normal distributions (Ruokolainen and Salo 2006). For these reasons, NMDS is widely used in analyses of community change (McCune and Grace 2002; Greenstein and Pandolfi 2008; Pucko et al. 2011).

Trend Detection for Ecological Condition at the Network Scale

Finally, we will use RIVPACS modeling as an approach for the detection of changes in ecological condition at the network scale. We will establish a temporal baseline using macroinvertebrate and/or diatom data collected at a large set of reference sites collected over a limited period of time (2004–2011). These data have been collected by the CAKN, the U.S. Geological Survey, and Alaska DEC using field and laboratory methods that are the same or very similar. This will constitute the third iteration of the CAKN RIVPACS model and is currently under development. Significant deviations from expectations in O/E scores at individual sites (defined as being less than the 10th percentile or greater than the 90th percentile of the distribution of reference site O/E scores), or in median O/E score at the park or network scale can be interpreted as indicating a significant change in community composition. To assess whether ecological condition at the park or network scale (or any other grouping of interest) has changed from baseline expectations, reference site data collected after the baseline period will be evaluated against the reference site data used to develop the RIVPACS

model. The Mann-Whitney test, or the Kruskal-Wallis test, will be used to test whether the typical site in the group under evaluation (e.g., all sites in DENA sampled from 2014–2016) is statistically different from the baseline reference site group (Helsel and Hirsch 2002). Because the majority of streams in the CAKN are not subject to traditional anthropogenic stressors, any such alterations will likely indicate the effects of climate change.

Trend Detection for Hydrologic Regime

We will rely on the U.S. Geological Survey, Alaska Science Center Water Resources office for analysis of and reporting on streamflow data from the existing gaging station on the Yukon River. The formal station ID for this gage is USGS 15356000 YUKON R AT EAGLE AK. Real-time stage and discharge data are available for this station at

https://waterdata.usgs.gov/ak/nwis/uv?site_no=15356000. Historical data and flow statistics are published at https://waterdata.usgs.gov/nwis/inventory/?site_no=15356000&agency_cd=USGS.

Under the current cooperative operating agreement for the Nabesna River gaging station, U.S. Fish and Wildlife Service Water Resources Branch staff are responsible for data management, analysis, and reporting on streamflow data from the station. Standard methods of seasonally adjusted time series analysis, specifically the seasonal Mann-Kendall test (Helsel and Hirsch 2002; Hirsch and Slack 1984), will be used to look for long term trends in flow data. Where appropriate, the partial Mann-Kendall test will be used to adjust for the effects of environmental covariates on trends in flow (Libiseller and Grimvall 2002).

Personnel Requirements and Training

Roles and Responsibilities

The project manager will be the lead ecologist for implementing the monitoring protocol, and will be supervised by the network coordinator for the Central Alaska Network. Currently the project manager is the CAKN aquatic ecologist. The project manager will typically be responsible for implementing the protocol and will work with contractors to ensure the completion of all tasks in a timely manner. The project manager will also be responsible for training personnel in implementing the protocol to collect high-quality data that comply with all QA/QC procedures for data collection and management. The project manager will ensure that all procedures outlined in SOP 16: Field Season Demobilization are followed; will be actively involved in the collection, entry, verification, validation, and summary of data; and together with the data manager will ensure the quality and security of the data.

Qualifications and Training

The single most critical component to maintaining a good monitoring program is having well-trained and competent personnel. There are very specific methods for collecting water samples and measuring the physical, chemical, and biological attributes of aquatic ecosystems. It is essential that personnel be properly trained in calibrating and operating all measuring tools and equipment and in the execution of those tasks in a safe manner.

Training will consist of office and laboratory training in procedures, equipment, supplies, sample tracking, sample handling, and data management. Once all crew members have been trained in the laboratory, training sessions will be conducted at nearby streams to ensure that all personnel are comfortable with the procedures and that all equipment is working properly. Initial field visits should be to easily accessible streams to facilitate troubleshooting, repairs, and revision of methods (should such be necessary) prior to being dropped in remote locations with little opportunity for correction.

In addition to this program-specific training, all personnel will complete required safety training, including wilderness first aid, CPR, bear safety, non-law-enforcement firearm certification, and aviation safety, as well as other training that may be necessary for the completion of field activities (e.g., ATV training, motorboat operator certification, underwater egress (“dunker”) training, etc.). SOP 4: Training addresses training requirements in more detail for each monitoring element.

Crew Size and Composition

Each sampling crew requires two to three people, depending on which variables will be sampled and the form of transportation. Although much of the protocol can be carried out by a single crewmember, including collection of water chemistry and biological samples, safety considerations require that field crews always consist of at least two people. When using two-person aircraft or small helicopters for transportation, it can be very efficient if the pilot is willing and able to serve as a crew member. Although the complete protocol can be completed by a two-person crew in three to four hours, having a crew of three allows for more rapid completion of the sampling. However, due to the difficulties and expense of transporting a three-person crew and associated equipment in small

fixed-wing aircraft or small helicopters, the costs of transport can quickly outweigh the benefit of having additional personnel at the field site.

Operational Requirements

Annual Workload and Field Schedule

Stream and river monitoring will begin in mid-May and extend through mid- to late September. Early and late season sampling will be restricted to minimal data collection at road-accessible sites and will require only the network aquatic ecologist. The bulk of data collection will occur during an index period from late June through late August. These sampling efforts will require a two- or three-person field crew. Field sampling trips will generally be scheduled to be five to seven days long. This time frame allows adequate time for sampling a large number of streams and provides ample time for logistical access, while staying within the allowable holding times for all water samples.

Facility Requirements

The stream and river monitoring program does not require any additional facilities beyond normal office and laboratory space and equipment storage. Chemicals for calibration and preservation must be stored in the appropriate storage containers and cabinets. All chemicals and samples will be accompanied by an accurate and updated MSDS sheet.

Budget Requirements

Personnel expenses for field work are based on a crew of two people: an ecologist to conduct and supervise sampling and a trained hydrologic technician, biotech, or volunteer (Table 13). Currently, field crews consist of the network aquatic ecologist plus a seasonal biotech provided by Yukon-Charley Rivers/Gates of the Arctic National Parks and Preserves (YUGA). Field costs will vary from year to year depending on the accessibility of targeted streams, the method of access (motor vehicle, motor boat, fixed wing, or helicopter), and the number of streams to be sampled. Difficult to predict factors, including aircraft reassignment, wildfire, and inclement weather, can have a significant impact on the actual number of sites that can be sampled in any given year, which in turn can have unpredictable effects on the total cost of the program for that year. The core program, which consists of sampling only the accessible sentinel and synoptic sites, will have very low field costs, since all of these sites can be accessed by road or motor boat. Noncore sites, all of which are synoptic sites, generally require the use of helicopters. Accordingly, as the price of helicopter flight time increases, we will be forced to reduce the number of noncore sites we visit each year, absent increases in our budget.

Table 13. Annual estimated budget breakdown for the CAKN Stream Monitoring Program. Costs are current as of 2016. Travel costs, flight time costs and miscellaneous costs are approximate, and are based on the average annual expenditures from 2010-2015.

Budget item	Pay periods	Estimated annual cost	Funding source
GS-12 Aquatic Ecologist	26	\$124,540	CAKN
GS-5 Biotech	2	\$3560	YUGA
GS-9 Data manager	1	\$3345	CAKN
GS-12 Biometrician	1	\$4790	CAKN
Laboratory costs, water chemistry (25 samples)	NA	\$7360	WRD
Laboratory costs, macroinvertebrates (25 samples)	NA	\$7550	WRD
Laboratory costs, diatoms (25 samples)	NA	\$8600	WRD
Travel costs for field work	NA	\$3100	WRD
Flight time costs for field work	NA	\$9500	WRD
Miscellaneous costs (gear replacement and repair, etc.)	NA	\$2700	WRD

Laboratory costs, while relatively stable, constitute a substantial expense (currently just over \$23,000 per year for 25 sites) and will increase gradually due to inflation; in the absence of budgetary increases for the monitoring program, these costs will eventually force a reassessment of the number of sites that can be sampled each year or of the sample types to be collected. For example, laboratory costs (at current prices) would drop to \$13,000 if only the sentinel sites were sampled. Alternatively, if diatom sampling were discontinued, the laboratory cost of sampling 25 sites would drop to \$15,000 per year. These decisions will be addressed as needed in the future. At present, the average total cost of the stream monitoring program is approximately \$175,000. Of that figure, \$132,675 comes from the CAKN monitoring budget, \$3560 comes from the YUGA budget, and \$38,810 comes from the NPS Water Resources Division.

Protocol Revision and Archiving

One of the most important aspects of any long-term monitoring program is documenting any changes that occur as the program develops and matures. Every monitoring program changes as technology advances and the program learns about the ecosystem. It is important to make adaptations to the program to ensure that the data are of high quality, to justify continued spending, and to maximize our understanding of the ecosystem. To help track these changes we have developed a system to track revisions and archiving of methodologies. We have also included a review history that explains the revision history so that others may see the reviewers' comments on the program as it has developed.

Protocol Structure

The Stream Monitoring Protocol includes three layers of documents:

1. Protocol Narrative
2. Standard Operating Procedures
3. Instruction Sheets

The protocol was divided into these three layers in order to streamline the documents and to acknowledge the different degrees to which protocols will require revision. The Protocol Narrative is a general overview of the protocol, which gives the history and justification for doing the work and an overview of the sampling methods, but does not provide all of the methodological details. The Protocol Narrative will only be revised if major changes are made to the protocol.

The Standard Operating Procedures are detailed instructions for performing a given task. They are expected to be revised more frequently than the protocol narrative, as new methods or technologies emerge or equipment changes are required. Often these changes will not impact the content of the Protocol Narrative. Each SOP contains a Revision History Log, which should be filled out each time a SOP is revised to explain why the change was made and to assign a new version number to the revised SOP. The previous version will be archived in accordance with SOP 18: Revising the Protocol.

Instruction Sheets are very detailed, step-by-step instructions for completing specific tasks required by the SOPs. This project makes use of many different technologies, electronics, and software, many of which require either extensive experience or detailed instructions for successful use. These tools tend to change quite frequently as updates are released or new and more appropriate tools become available. If all of the detailed instructions are included in the SOP documents, it makes them unwieldy to read and also requires more frequent revisions of the SOP documents. In addition, many of the different SOPs refer to the same programs or procedures, and rather than listing them repeatedly within each SOP, they can all simply refer to the appropriate Instruction Sheet. These Instruction Sheets are produced in a stand-alone format, which allows the instructions for a specific procedure to be printed out for easy reference in the field. Again, these documents will be archived as new versions are produced, and the most recent versions of the Instruction Sheets should be available

as individual documents on the NPS Natural Resource Information Portal and/or the network website(s) for this project. The published protocol will not necessarily be updated for changes at the Instruction Sheet level, but the individual Instruction Sheet documents available for download should be kept up-to-date.

Revision Procedures

Over time, revisions to both the Protocol Narrative and to specific SOPs are to be expected. Careful documentation of changes to the protocol, and a library of previous protocol versions, are essential for maintaining consistency in data collection, for appropriate treatment of the data during data summary and analysis, and for tracking important changes in detection and reporting limits for water quality monitoring. The STORET database for each monitoring component contains a field that identifies which version of the protocol was being used when the data were collected.

The steps for changing any portion of the protocol are outlined in SOP 18: Revising the Protocol. The protocol should be produced using the templates for the NPS NRTR series. All versions of the Protocol Narrative, the Standard Operating Procedures, and Instruction Sheets should be archived appropriately.

The protocol in its entirety must be posted in the NPS Inventory and Monitoring Division's Protocol Tracker Database: <https://irma.nps.gov/protocoltracking/>

Protocols are available to the public at the CAKN website:
<http://science.nature.nps.gov/im/units/cakn/>

The protocol is also available from the Natural Resource Publications Management website:
<http://www.nature.nps.gov/publications/nrpm/>

The protocol is also available from the Integrated Research Management Applications (IRMA) portal: <https://irma.nps.gov/DataStore/Reference/Profile/2215908>

It is imperative that only the current versions of each document are used in training field personnel and in conducting the subsequent monitoring. When changes are made, forward the new copy of the protocol to all individuals known to have a previous version.

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NPS 953/138880, June 2017

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